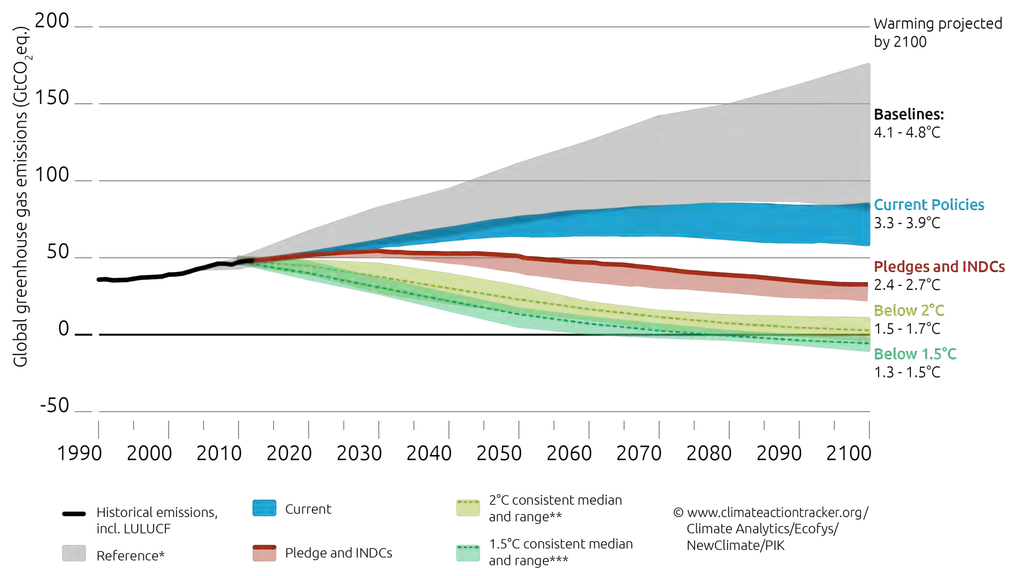
CLIMATE ACTION TRACKER

104

Effect of current pledges and policies on global temperature



* 5%-95% percentile of AR5 WGIII scenarios in concentration category 7, containing 64% of the baseline scenarios assessed by the IPCC
** Greater than 66% chance of staying within 2°C in 2100. Median and 10th to 90th percentile range. Pathway range excludes delayed action scenarios and any that deviate more than 5% from historic emissions in 2010.
*** Greater than or equal to 50% chance of staying below 1.5°C in 2100. Median and 10th to 90th percentile range. Pathway range excludes delayed action scenarios and any that deviate more than 5% from historic emissions in 2010.

Data underlying the above graph can be downloaded here.

Addressing global warming

In the absence of policies global warming is expected, to reach 4.1°C – 4.8°C above pre-industrial by the end of the century. The emissions that drive this warming are often called **Baseline** scenarios ('Baselines' in the above figure). and are taken from the IPCC AR5 Working Group III. **Current policies** presently in place around the world are projected to reduce baseline emissions and result in about 3.6°C [1] warming above pre-industrial levels. The unconditional **pledges** or promises that governments have made, including in submitted **INDCs** as of 7 December 2015, would limit warming to about 2.7°C [2] above pre-industrial levels, or in probabilistic terms, likely limit warming below 3°C.

There remains a substantial gap between what governments have promised to do and the total level of actions they have undertaken to date. Furthermore, both the current policy and pledge trajectories lie well above emissions pathways consistent with a 1.5°C or 2°C world.

Evaluating progress towards the below 2°C and 1.5°C limits

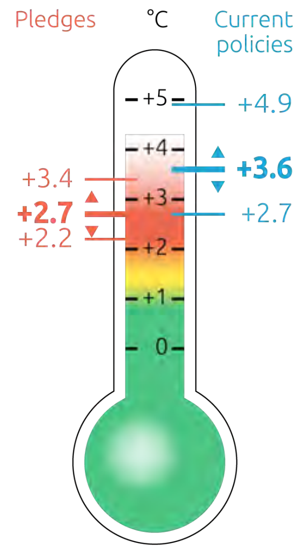
Limiting warming to the globally agreed goal of holding warming below a 2°C increase above pre-industrial in the 21st century means that the emissions of greenhouse gases need to be reduced rapidly in the coming years and decades, and brought to zero shortly after mid-century. Vulnerable countries, small island states and least developed countries, have called for warming to be limited to below 1.5°C by 2100. As a consequence the adequacy of the 2°C limit is being reviewed in a formal UNFCCC process where the merits of the 1.5°C limit are also being examined [3].

The CAT evaluates progress towards these global goals by quantifying the aggregate effects of current policies and the pledges (promises) and INDCs put forward by countries, and compares these with the emissions levels consistent over time with both the 1.5°C and 2°C warming limits.

The CAT Thermometer explained

The temperatures on the CAT thermometer are 'median' warming estimates in 2100. It means that there is a 50% chance that the calculated temperature would be exceeded if the given emissions pathway were followed.

For example, our emissions pathway in the **pledge** scenario (that incorporates **INDCs** until 7 December) gives a 50% chance of warming being 2.7°C or higher in 2100.



Using probabilities to provide more information

The 'median' is based on the probability distribution generated by the climate model (MAGICC) when it takes into account uncertainties in our knowledge of climate sensitivity, the carbon cycle, and effect of greenhouse gases, aerosols, and other factors that are used to calculate the temperatures. The probability distribution enables us to provide more information for policy makers and stakeholders about the likelihood of goals being met, or specific temperatures being exceeded.

December 2015 - INDCs likely below 3°C and over 90% chance exceeding 2°C

The emissions pledge pathway that includes INDCs has aover 90% probability of exceeding 2°C, and only a 'likely' (>66%) chance of remaining below 3°C this century. The current policy pathways have a higher than 99.5% probability of exceeding 2°C.

Limiting warming to 2°C with 'likely' probability

In the CAT we assess pathways against a (>66%) probability of holding warming below 2°C. A median 2°C pathway would give, in effect, only a 'toss of the coin' chance of limiting warming below this level. It is assumed that policy makers are interested in a higher probability of achieving this limit. A higher probability of limiting warming below 2°C gives greater confidence that the emissions reduction efforts made will be successful in limiting warming to 2°C. This means, of course, that the median peak warming from a 2°C compatible pathway will be lower than 2°C - in the range of 1.5-1.7°C (see figure above and IPCC AR5 WGIII Ch6).

What governments need to do to achieve the global goal

Fortunately, as shown by the IPCC AR5, substantially more action, sufficient to hold warming below 2°C (and to below 1.5°C by 2100) with likely probability is technically and economically feasible. According to the IPCC, the costs of reducing emissions to limit warming to below 2°C are modest, even before taking into account co-benefits such as increased energy-security and health improvements due to reduced air pollution. Annualised reductions of consumption growth are estimated at around 0.06 per cent over the century, relative to a baseline of 1.6 to 3% growth per year.[4]

The IPCC AR5 shows that even starting from emission levels implied by INDCs and current policy projections, 1.5°C and 2°C pathways are still technically feasible. However, the resulting emission pathways are increasingly expensive as they are not consistent with the most cost-efficient policies. Slower-than-optimal emission reductions early on need to be followed by faster reductions later on, effectively leading to significantly higher costs for the period 2030–2050 than would otherwise be needed. While the challenges are significant, limiting warming to below 1.5°C by the end of the century is still feasible from current emissions levels. However, with every decade lost, these challenges and costs rise and will, at some point, become insurmountable with warming locked in to 1.5 or 2°C and above.[5]

Further information
For more information on the global emission pathways and how they are calculated, please see the detailed analysis and methodology pages.

If you use the provided data or any of the graphs provided on this website, please make sure to reference the Climate Action Tracker and the Ecofys / Climate Analytics / New Climate / PIK team!

Last temperature update: 7 December 2015. 'Pledges' include all INDCs submitted by 7 December.

[1] 3.6 is the median of the low and high ends of current policy projections (3.3 to 3.8°C). The uncertainty range on the figure (2.7-4.9°C) originates from carbon-cycle and climate modelling around both the low and high current policy projections. Here we give the 68% range; that is the 16th and 84th percentiles of the probability distribution.

[2] The uncertainty range for pledges on the CAT thermometer (2.2-3.4°C) originates from carbon-cycle and climate modelling around both the low and high current policy projections. Here we give the 68% range; that is the 16th and 84th percentiles of the probability distribution. If the more ambitious end of pledge ranges were reached, warming could be limited to a median of 2.5°C. This includes the upper end of country INDCs where a reduction range is specified (e.g. the 28% end of the 26-28% commitment by the USA), and mitigation commitments that are conditional on finance (e.g. 101 Mt CO2-e by Trinidad & Tobago).

[3] http://unfccc.int/science/workstreams/the_2013-2015_review/items/6998.php

[4] The IPCC AR5 WGIII identified many mitigation options to hold warming below 2°C (with a likely chance), and with central estimates of 1.5-1.7°C by 2100. The IPCC further shows that "a limited number of studies have explored scenarios that are more likely than not to bring temperature change back to below 1.5°C by 2100". The scenarios indicating the feasibility of bringing temperatures down below 1.5°C are "characterised by (1) immediate mitigation action; (2) the rapid upscaling of the full portfolio of mitigation technologies; and (3) development along a low-energy demand trajectory." (IPCC WGIII SPM page 17). The 0.06 per cent figure is median of the range 0.04 to 0.14, Table SPM.2, IPCC AR5 WGIII page 15. For consumption growth figures refer to page 16.

[5] Refer to CAT Briefing "The CAT Emissions Gap - How close are INDCs to 1.5 and 2 pathways?", September 2015.

Federal Forest Carbon Coalition

Home | More info | Recommendations | Webinars | Email Updates

Recommendations

Modernizing Federal Forest Management To Mitigate and Prepare For Climate Disruption

Science-based Recommendations to The Obama Administration in Response to The President's November 1, 2013 Executive Order: Preparing the United States for the Impacts of Climate Change

PDF of Recommendations.

PDF of Summary of Recommendations.

Press Release (below)

June 26, 2014

Forest Carbon Coalition Urges The Obama Administration To Modernize Forest Management to Protect The Climate

Contact:

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Ernie Niemi, Co-Chair FFCC: ernie.niemi@nreconomics.com (delayed response)

Jim Furnish, Senior Advisor to the FFCC: (240) 271-1650 or jimfurnish@verizon.net

Eugene, Oregon and Washington D.C.: The Federal Forest Carbon Coalition (FFCC), today issued a suite of science-based recommendations to the Obama Administration intended to modernize federal forest management to address the climate crisis. The recommendations, Modernizing Federal Forest Management To Mitigate and Prepare For Climate Disruption, emphasize conserving carbon already stored in forests while also increasing carbon sequestration, building resilience to climate change-related disturbances, and generating social, economic, and ecological co-benefits consistent with the other goals.

The FFCC is a new first-of-a-kind consortium of over 60 national, regional and local organizations focused on forests, biodiversity, fisheries, rivers, faith and spirituality, Native American treaty rights, youth, rural communities, and climate disruption.

(Website: www.forestcc.org)

The FFCC's 17 recommendations are framed around six new interrelated goals that the FFCC believes are needed to help the U.S. Departments of Interior and Agriculture and other federal land management agencies comply with the requirements of President Obama's Executive Order 13653, of November 1, 2013: Preparing the United States for the Impacts of Climate Change. The President's Executive Order requires federal agencies to submit plans to CEQ and OMB by July of this year to build resilience for and reduce the sources of climate disruption.

“Although few people realize it, forests play a major role in regulating the Earth's climate, and federal forests must play a significant role in preventing runaway climate disruption,” said Bob Doppelt, Executive Director of the Resource Innovation Group, and co-chair of the FFCC. “To address this need, federal forest management agencies must rapidly make a major shift in mindset, science, policies, regulations, and practices. Our recommendations are intended to help the agencies begin the transition.”

“The economic values at stake are large,” said Ernie Niemi, economist with Natural Resource Economics Inc. and co-chair of the FFCC. “For example, using the Obama Administration's own $50 per metric tonne mid-level estimate of the social cost of carbon, if even one tenth of the carbon held on federal forests is released into the atmosphere the damage would be in the range of $200 billion. Our recommendations seek to reorient the management of federal forests to hold onto the stored carbon and prevent this major economic damage."

"Federal agencies have historically neglected forest carbon," said Jim Furnish, former Deputy Chief of the U.S. Forest Service and Senior Advisor to the FFCC. "We have identified several key policy changes that can really improve carbon storage and lessen climate change impacts."

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The complete set of FFCC recommendations can be obtained at the bottom of this page or this link:

http://www.theresourceinnovationgroup.org/storage/ffcc/FFCCrecommendationsToObamaAdminJune2014.pdf

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Statements From FFCC Steering Committee Members:

"For the sake of all children we believe that agencies who manage federal forests need to re-think and re-prioritize the purposes and practices of forest management in light of the present day climate reality," said Valerie Serrels, Associate Director of Kids vs Global Warming and the iMatter Campaign, and FFCC steering committee member. "Our recommendations provide a map for not only reframing forest management, but also for transformational shifts in understanding the context of forestry within today's new climate paradigm."

"We love our forests for their beauty and for providing an abundance of clean water, wildlife, and recreation," said Shelley Silbert, Executive Director of Great Old Broads for Wilderness and FFCC Steering committee member. "However, when we think of the economic value of forests, we fail to recognize their critical importance in regulating climate disruption. Reorienting the management of our National Forests is essential to our future."

"The Tongass is a shining knight in the battle against global warming, and must be managed to protect its world-class ability to store carbon," said Malena Marvin, Executive Director at Southeast Alaska Conservation Council and FFCC Steering Committee member. "The good news is that protecting Tongass carbon storage is 100% compatible with a Tongass transition that also prioritizes Southeast Alaska's forest jobs and our $2 billion per year fishing and tourism industries."

"From the massive Coast Redwoods of California to the towering spruce trees of the Tongass rainforest in Alaska, older forests help stabilize the climate, clean our air, give us drinking water, and support the region's outdoor economies," said Dominick A. DellaSala, Ph.D, President, Chief Scientist at the Geos Institute and an FFCC Steering committee member. "The President can make protecting the nation's older forests a signature part of his environmental and climate change legacy."

"If we let them, our public forests can live for centuries, making them great places to store carbon and reduce greenhouse pollution," said Doug Heiken of Oregon Wild and an FFCC steering committee member. "Conserving high-carbon forests will not only help stabilize the climate, but provide a variety of additional benefits, such as clean water, wildlife habitat, and recreation, all of which enhance our quality of life."

PDF of Recommendations.

PDF of Summary of Recommendations.

Subpages (1): GHG NEPA Comments

FFCCrecommendationsToObamaAdminJune2014.... TRIG CLI, Jun 25, 2014, 6:26 PM v.4

the WHITE HOUSE

Incorporating Natural Infrastructure and Ecosystem Services in Federal Decision-Making

OCTOBER 7, 2015 AT 2:30 PM ET BY TAMARA DICKINSON, TIMOTHY MALE, ALI ZAIDI

Summary: Today, the Administration released a new memorandum directing Federal agencies to factor the value of ecosystem services into Federal planning and decision-making.

Our natural world provides critical contributions that support and protect our communities and economy. For instance, Louisiana's coastal wetlands provide billions of dollars worth of flood protection and other benefits. Preserving and restoring forests in the Catskill Mountains enables New York City to access clean water at a cost several times less than the cost of building a new water-filtration plant. And current efforts to plant trees along Oregon's salmon-rich rivers will improve local water quality – saving costs associated with installing expensive machinery to achieve the same purpose.

These are just a few examples of the many ways that nature creates benefits that contribute to our economic prosperity, protect the health and safety of vulnerable populations, and help build more resilient communities. But these "ecosystem services" are often overlooked. Integrating ecosystem services into planning and decision-making can lead to better outcomes, fewer unintended consequences, and more efficient use of taxpayer dollars and other resources.

That is why, today, the Administration is issuing a memorandum directing all Federal agencies to incorporate the value of natural, or "green," infrastructure and ecosystem services into Federal planning and decision making. The memorandum directs agencies to develop and institutionalize policies that promote consideration of ecosystem services, where appropriate and practicable, in planning, investment, and regulatory contexts. It also establishes a process for the Federal government to develop a more detailed guidance on integrating ecosystem-service assessments into relevant programs and projects to help maintain ecosystem and community resilience, sustainable use of natural resources, and the recreational value of the Nation's unique landscapes.

This memorandum complements *Ecosystem-Service Assessment: Research Needs for Coastal Green Infrastructure*, a report released by the Administration in August that outlines Federal research priorities to inform the integration of coastal green infrastructure and ecosystem services considerations into planning and decision-making. Together, they showcase continued Federal progress in response to recent recommendations made by the President's Council of Advisors on Science and Technology, the Hurricane Sandy Task Force; the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience; and the White House Council on Climate Preparedness and Resilience.

Moreover, today's memorandum builds on complementary efforts across the Obama Administration. For example:

- In 2012, the **U.S. Forest Service** issued a planning rule for National Forest System land-management planning. The rule established policies to better value and protect ecosystem services on 193 million acres of National Forest.
- In August, the **Gulf Coast Ecosystem Restoration Council** released for public comment a draft list of projects, using funds from the settlement with Transocean Deepwater Inc. for initial investments, which will invest in restoring natural barriers to future storms and other resources critical to the health and safety of local communities and their economies.
- In September, the **U.S. Environmental Protection Agency** and the **U.S. Department of Agriculture** hosted a workshop in Lincoln, Nebraska on water-quality markets and the importance of quantifying ecosystem services to support water quality trading and other innovative approaches to mitigating environmental damages.

President Obama has taken unprecedented action to combat climate change, while also ensuring that Federal investments are climate resilient and made with anticipated future conditions in mind. Today's actions, and future actions and events, will enhance our ability to recognize and leverage the benefits of natural systems, protect against natural hazards, and support social and economic development while keeping our communities and our world healthy and livable.

Tamara Dickinson is Principal Assistant Director for Environment & Energy at the White House Office of Science and Technology Policy.

Timothy Male is Associate Director for Conservation and Wildlife at the Council on Environmental Quality.

Ali Zaidi is Associate Director for Natural Resources, Energy, and Science at the White House Office of Management and Budget.

THE FINAL STATE OF THE UNION

Watch President Obama's final State of the Union address.

THE SUPREME COURT

Read what the President is looking for in his next Supreme Court nominee.

FIND YOUR PARK

Take a look at America's three newest national monuments.

The White House
Office of the Press Secretary

For Immediate Release November 03, 2015

Presidential Memorandum: Mitigating Impacts on Natural Resources from Development and Encouraging Related Private Investment

MEMORANDUM FOR THE SECRETARY OF DEFENSE
THE SECRETARY OF THE INTERIOR

THE SECRETARY OF AGRICULTURE
THE ADMINISTRATOR OF THE ENVIRONMENTAL PROTECTION AGENCY
THE ADMINISTRATOR OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

We all have a moral obligation to the next generation to leave America's natural resources in better condition than when we inherited them. It is this same obligation that contributes to the strength of our economy and quality of life today. American ingenuity has provided the tools that we need to avoid damage to the most special places in our Nation and to find new ways to restore areas that have been degraded.

Federal agencies implement statutes and regulations that seek simultaneously to advance our economic development, infrastructure, and national security goals along with environmental goals. As efforts across the country have demonstrated, it is possible to achieve strong environmental outcomes while encouraging development and providing services to the American people. This occurs through policies that direct the planning necessary to address harmful impacts on natural resources by avoiding and minimizing impacts, then compensating for impacts that do occur. Moreover, when opportunities to offset foreseeable harmful impacts to natural resources are available in advance, agencies and project proponents have more options to achieve positive environmental outcomes and potentially reduce permitting timelines.

Federal agencies can, however, face barriers that hinder their ability to use Federal resources for restoration in advance of regulatory approval of development and other activities (e.g., it may not be possible to fund restoration before the exact location and scope of a project have been approved; or there may be limitations in designing large-scale management plans when future development is uncertain). This memorandum will encourage private investment in restoration and public-private partnerships, and help foster opportunities for businesses or non-profit organizations with relevant expertise to successfully achieve restoration and conservation objectives.

One way to increase private investment in natural resource restoration is to ensure that Federal policies are clear, work similarly across agencies, and are implemented consistently within agencies. By encouraging agencies to share and adopt a common set of their best practices to mitigate for harmful impacts to natural resources, the Federal Government can create a regulatory environment that allows us to build the economy while protecting healthy ecosystems that benefit this and future generations. Similarly, in non-regulatory circumstances, private investment can play an expanded role in achieving public natural resource restoration goals. For example, performance contracts and other Pay for Success approaches offer innovative ways to finance the procurement of measurable environmental benefits that meet high government standards by paying only for demonstrated outcomes.

Therefore, by the authority vested in me as President by the Constitution and the laws of the United States of America, and to protect the health of our economy and environment, I hereby direct the following:

Section 1. Policy. It shall be the policy of the Departments of Defense, the Interior, and Agriculture; the Environmental Protection Agency; and the National Oceanic and Atmospheric Administration; and all bureaus or agencies within them (agencies); to avoid and then minimize harmful effects to land, water, wildlife, and other ecological resources (natural resources) caused by land- or water-disturbing activities, and to ensure that any remaining harmful effects are effectively addressed, consistent with existing mission and legal authorities. Agencies shall each adopt a clear and consistent approach for avoidance and minimization of, and compensatory mitigation for, the impacts of their activities and the projects they approve. That approach should also recognize that existing legal authorities contain additional protections for some resources that are of such irreplaceable character that minimization and compensation measures, while potentially practicable, may not be adequate or appropriate, and therefore agencies should design policies to promote avoidance of impacts to these resources.

Large-scale plans and analysis should inform the identification of areas where development may be most appropriate, where high natural resource values result in the best locations for protection and restoration, or where natural resource values are irreplaceable. Furthermore, because doing so lowers long-term risks to our environment and reduces timelines of development and other projects, agency policies should seek to encourage advance compensation, including mitigation bank-based approaches, in order to provide resource gains before harmful impacts occur. The design and implementation of those policies should be crafted to result in predictability sufficient to provide incentives for the private and non-governmental investments often needed to produce successful advance compensation. Wherever possible, policies should operate similarly across agencies and be implemented consistently within them.

To the extent allowed by an agency's authorities, agencies are encouraged to pay particular attention to opportunities to promote investment by the non-profit and private sectors in restoration or enhancement of natural resources to deliver measurable environmental outcomes related to an established natural resource goal, including, if appropriate, as part of a restoration plan for natural resource damages or for authorized investments made on public lands.

Sec. 2. Definitions. For the purposes of this memorandum:

(a) "Agencies" refers to the Department of Defense, Department of the Interior, Department of Agriculture, Environmental Protection Agency, and National Oceanic and Atmospheric Administration, and any of their respective bureaus or agencies.

(b) "Advance compensation" means a form of compensatory mitigation for which measurable environmental benefits (defined by performance standards) are achieved before a given project's harmful impacts to natural resources occur.

(c) "Durability" refers to a state in which the measurable environmental benefits of mitigation will be sustained, at minimum, for as long as the associated harmful impacts of the authorized activity continue. The "durability" of a mitigation measure is influenced by: (1) the level of protection or type of designation provided; and (2) financial and long-term management commitments.

(d) "Irreplaceable natural resources" refers to resources recognized through existing legal authorities as requiring particular protection from impacts and that because of their high value or function and unique character, cannot be restored or replaced.

(e) "Large-scale plan" means any landscape- or watershed-scale planning document that addresses natural resource conditions and trends in an appropriate planning area, conservation objectives for those natural resources, or multiple stakeholder interests and land uses, or that identifies priority sites for resource restoration and protection, including irreplaceable natural resources.

(f) "Mitigation" means avoiding, minimizing, rectifying, reducing over time, and compensating for impacts on natural resources. As a practical matter, all of these actions are captured in the terms avoidance, minimization, and compensation. These three actions are generally applied sequentially, and therefore compensatory measures should normally not be considered until after all appropriate and practicable avoidance and minimization measures have been considered.

Sec. 3. Establishing Federal Principles for Mitigation. To the extent permitted by each agency's legal authorities, in addition to any principles that are specific to the mission or authorities of individual agencies, the following principles shall be applied consistently across agencies to the extent appropriate and practicable.

(a) Agencies should take advantage of available Federal, State, tribal, local, or non-governmental large-scale plans and analysis to assist in identifying how proposed projects potentially impact natural resources and to guide better decision-making for mitigation, including avoidance of irreplaceable natural resources. 4

(b) Agencies' mitigation policies should establish a net benefit goal or, at a minimum, a no net loss goal for natural resources the agency manages that are important, scarce, or sensitive, or wherever doing so is consistent with agency mission and established natural resource objectives. When a resource's value is determined to be irreplaceable, the preferred means of achieving either of these goals is through avoidance, consistent with applicable legal authorities. Agencies should explicitly consider the extent to which the beneficial environmental outcomes that will be achieved are demonstrably new and would not have occurred in the absence of mitigation (i.e. additionality) when determining whether those measures adequately address impacts to natural resources.

(c) With respect to projects and decisions other than in natural resource damage cases, agencies should give preference to advance compensation mechanisms that are likely to achieve clearly defined environmental performance standards prior to the harmful impacts of a project. Agencies should look for and use, to the extent appropriate and practicable, available advance compensation that has achieved its intended environmental outcomes. Where advance compensation options are not appropriate or not available, agencies should give preference to other compensatory mitigation practices that are likely to succeed in achieving environmental outcomes.

(d) With respect to natural resource damage restoration plans, natural resource trustee agencies should evaluate criteria for whether, where, and when consideration of restoration banking or advance restoration projects would be appropriate in their guidance developed pursuant to section 4(d) of this memorandum. Consideration under established regulations of restoration banking or advance restoration strategies can contribute to the success of restoration goals by delivering early, measurable environmental outcomes.

(e) Agencies should take action to increase public transparency in the implementation of their mitigation policies and guidance. Agencies should set measurable performance standards at the project and program level to assess whether mitigation is effective and should clearly identify the party responsible for all aspects of required mitigation measures. Agencies should develop and use appropriate tools to measure, monitor, and evaluate effectiveness of avoidance, minimization, and compensation policies to better understand and explain to the public how they can be improved over time.

(f) When evaluating proposed mitigation measures, agencies should consider the extent to which those measures will address anticipated harm over the long term. To that end, agencies should address the durability of compensation measures, financial assurances, and the resilience of the measures' benefits to potential future environmental change, as well as ecological relevance to adversely affected resources.

(g) Each agency should ensure consistent implementation of its policies and standards across the Nation and hold all compensatory mitigation mechanisms to equivalent and effective standards when implementing their policies.

(h) To improve the implementation of effective and durable mitigation projects on Federal land, agencies should identify, and make public, locations on Federal land of authorized impacts and their associated mitigation projects, including their type, extent, efficacy of compliance, and success in achieving performance measures. When compensatory actions take place on Federal lands and waters that could be open to future multiple uses, agencies should describe measures taken to ensure that the compensatory actions are durable.

Sec. 4. Federal Action to Strengthen Mitigation Policies and Support Private Investment in Restoration. In support of the policy and principles outlined above, agencies identified below shall take the following specific actions.

(a) Within 180 days of the date of this memorandum, the Department of Agriculture, through the U.S. Forest Service, shall develop and implement additional manual and handbook guidance that addresses the agency's approach to avoidance, minimization, and compensation for impacts to natural resources within the National Forest System. The U.S. Forest Service shall finalize a mitigation regulation within 2 years of the date of this memorandum.

(b) Within 1 year of the date of this memorandum, the Department of the Interior, through the Bureau of Land Management, shall finalize a mitigation policy that will bring consistency to the consideration and application of avoidance, minimization, and compensatory actions or development activities and projects impacting public lands and resources.

(c) Within 1 year of the date of this memorandum, the Department of the Interior, through the U.S. Fish and Wildlife Service, shall finalize a revised mitigation policy that applies to all of the U.S. Fish and Wildlife Service's authorities and trust responsibilities. The U.S. Fish and Wildlife Service shall also finalize an additional policy that applies to compensatory mitigation associated with its responsibilities under the Endangered Species Act of 1973. Further, the U.S. Fish and Wildlife Service shall finalize a policy that provides clarity to and predictability for agencies and State governments, private landowners, tribes, and others that take action to conserve species in advance of potential future listing under the Endangered Species Act. This policy will provide a mechanism to recognize and credit such action as avoidance, minimization, and compensatory mitigation.

(d) Within 1 year of the date of this memorandum, each Federal natural resource trustee agency will develop guidance for its agency's trustee representatives describing the considerations for evaluating whether, where, and when restoration banking or advance restoration projects would be appropriate as components of a restoration plan adopted by trustees. Agencies developing such guidance will coordinate for consistency.

(e) Within 1 year of the date of this memorandum, the Department of the Interior will develop program guidance regarding the use of mitigation projects and measures on lands administered by bureaus or offices of the Department through a land-use authorization, cooperative agreement, or other appropriate mechanism that would authorize a project proponent to conduct actions, or otherwise secure conservation benefits, for the purpose of mitigating impacts elsewhere. 6

Sec. 5. General Provisions. (a) This memorandum complements and is not intended to supersede existing laws and policies.

(b) This memorandum shall be implemented consistent with applicable law, and subject to the availability of appropriations.

(c) This memorandum is intended for the internal guidance of the executive branch and is inapplicable to the litigation or settlement of natural resource damage claims. The provisions of section 3 this memorandum encouraging restoration banking and advance restoration projects also do not apply to the selection or implementation of natural resource restoration plans, except to the extent determined appropriate in Federal trustee guidance developed pursuant to section 4(d) of this memorandum.

(d) The provisions of this memorandum shall not apply to military testing, training, and readiness activities.

(e) Nothing in this memorandum shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department, agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(f) This memorandum is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.

(g) The Secretary of the Interior is hereby authorized and directed to publish this memorandum in the *Federal Register*.

BARACK OBAMA

# # #

CEQ Releases Final Guidance on Greenhouse Gases and Climate Change

The Council on Environmental Quality (CEQ) has released final guidance for Federal agencies on how to consider the impacts of their actions on global climate change in their National Environmental Policy Act (NEPA) reviews. This final guidance provides a framework for agencies to consider both the effects of a proposed action on climate change, as indicated by its estimated greenhouse gas emissions, and the effects of climate change on a proposed action. The final guidance applies to all types of proposed Federal agency actions that are subject to NEPA analysis and guides agencies on how to address the greenhouse gas emissions from Federal actions and the effects of climate change on their proposed actions within the existing NEPA regulatory framework. Below is the guidance and related information, including a list of greenhouse gas accounting tools available to Federal agencies.

- Read the Final Guidance on the Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in NEPA Reviews
- View list of available GHG accounting tools
- Read the fact sheet announcing CEQ's issuance of the Final Guidance
- Read the 2014 Revised Draft Guidance
- Read the 2010 Draft Guidance

Gulf Coast Ecosystem Restoration

Updated Principles and Guidelines for Water and Land Related Resources Implementation Studies

Carbon Capture & Storage

Rocky Mountain Bighorn Sheep (*Ovis canadensis*): A Technical Conservation Assessment

Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project

February 12, 2007

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Peer Review Administered by
Society for Conservation Biology

Beecham, J.J. Jr., C.P. Collins, and T.D. Reynolds. (2007, February 12). Rocky Mountain Bighorn Sheep (*Ovis canadensis*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/rockymountainbighornsheep.pdf [date of access].

ACKNOWLEDGMENTS

We thank the following biologists from the states of Colorado (Bruce Watkins), Wyoming (Doug McWhirter, Doug Brimeyer, Greg Anderson, Gary Fralick, Dean Clause, Stan Harter, and, especially, Kevin Hurley), South Dakota (Ted Benzon), and Nebraska (Gary Schlichtemeier and Dustin Darveau); and from the national forests within USDA Forest Service Rocky Mountain Region for their time and willingness to provide information for this species assessment of the status of Rocky Mountain bighorn sheep. We are particularly grateful to Idaho Department of Fish and Game biologists Dale Toweill and Frances Cassirer for their thoughtful reviews of early drafts of the document and to Jon Jorgenson (Alberta Fish and Wildlife) and an anonymous reviewer for helpful comments on the final draft. We thank Patricia Isaeff for assembling the envirogram into a useful display format, Jarod Blades for constructing many of the sheep-distribution figures, and Brandt Elwell for his quick and successful resolution of GIS imagery issues. Finally, the authors thank Gary D. Patton, Species Conservation Project Manager, and Melanie Woolever, Wildlife Program Manager, both with the USDA Forest Service Rocky Mountain Regional Office, for their guidance, direction, and patience. The authors are in debt to Ms. Kimberly Nguyen, Technical Specialist, for her help and patience in developing the final Web published product.

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Cover Photo Credit

Rocky Mountain bighorn ram (*Ovis canadensis canadensis*), Rocky Mountain National Park, Colorado. © Jesse Speer Photography. Used with permission.

List of Errata

Summary of Key Components for Conservation of the Rocky Mountain Bighorn Sheep

Two species of mountain sheep occur in western North America. Thinhorn mountain sheep (*Ovis dalli*) are found in Alaska and the Yukon, Northwest Territories, and British Columbia in Canada. The bighorn species (*O. canadensis*) was historically distributed from the Canadian provinces of British Columbia and Alberta south to Mexico. Rocky Mountain (*O. c. canadensis*) and a desert subspecies (*O. c. nelsoni*) of bighorn sheep are found within USDA Forest Service Region 2. This conservation assessment focuses on the Rocky Mountain bighorn sheep within Region 2.

Minimal human impacts and the remoteness of thinhorn mountain sheep habitat have resulted in relatively stable populations across their range. However, from the late 1800's through the mid-1900's, bighorn sheep populations experienced significant declines across their range as a result of diseases introduced from domestic livestock, unregulated and market hunting, habitat loss, and competition from domestic livestock. In the 1960's, many western states, including those in Region 2, began active bighorn sheep transplant programs in an effort to augment small, remnant sheep populations and to reintroduce bighorns into historic, but vacant, habitat. Although bighorn sheep numbers increased throughout the western United States because of these transplant efforts, periodic die-offs continued to occur in many herds, including those in Region 2. These die-offs appeared to result from transmission of pneumonia pathogens from domestic sheep (*Ovis* spp.), possibly in conjunction with environmental stressors.

Threats to the long-term viability of bighorn sheep in Region 2 include diseases transmitted by domestic livestock, the lack of connectivity and/or loss of genetic variability (fitness) due to habitat fragmentation, habitat loss, increased human disturbance, competition with domestic livestock, and predation on small, isolated herds. The relative importance of these threats to the persistence of bighorn sheep in Region 2 varies from area to area. However, the risk of disease outbreaks resulting from contact with domestic sheep and goats is widely believed to be the most significant threat facing bighorns in Region 2 and elsewhere across their range.

Despite these risks to population persistence, several areas can be considered strongholds for bighorns in Region 2. As evidenced by a history free of disease-related die-offs, these areas have a minimal risk of disease outbreaks, or if die-offs have occurred, the suspected causes (i.e., domestic sheep or goat herds) have been removed or significantly lessened. In addition, the individual bighorn populations in these areas are relatively large and exhibit a functioning metapopulation structure, ensuring a significant degree of genetic exchange among herds. Finally, habitat quality is not a limiting factor in terms of imposing impediments to seasonal migration or leading to poor herd health due to nutritional deficiencies. Obvious strongholds within Region 2 are found in northwestern Wyoming and south-central Colorado. Herd units in these two areas are well connected, allowing movement between populations; consist of some of the largest populations within Region 2; are free of disease-related die-offs; and occupy habitats where the threat of domestic sheep contact has been removed or dramatically reduced. Seasonal movements are not greatly impaired in these two areas, and habitat quality is not a limiting factor.

Several bighorn herds in Region 2 are at risk of extirpation from disease-related die-offs and/or chronically poor production, small population size, total or near complete isolation from other bighorn populations, major obstacles to seasonal movements, and poor habitat quality leading to poor nutrition. Most of these units are located in southwestern Colorado, but additional high-risk areas include South Dakota's Custer State Park population and all three herds in Nebraska. A large number of bighorn herds in Colorado and Wyoming possess both low- and high-risk characteristics. Because these herd units face fewer total threats, or less dire threats, than those in high-risk areas, they are most likely to benefit from the expenditure of management resources.

Management and conservation efforts for bighorn sheep in Region 2 should focus on:

1) eliminating the potential for contact between bighorn sheep and domestic sheep and goats

2) actively managing the female component of each herd to prevent the herd from exceeding the carrying capacity of its range

3) managing bighorns and their habitat in a metapopulation context by maintaining connectivity among subpopulations

4) developing and implementing a health screening process to complement translocation programs

5) periodically augmenting isolated bighorn subpopulations and reintroducing bighorns into historic habitats where suitable conditions exist

6) managing bighorn habitat to restore, enhance, or maintain vegetative openness adjacent to bighorn escape cover and along movement corridors

7) minimizing human disturbance in sensitive habitats (i.e., lambing and winter ranges)

8) implementing focused predator removal efforts in areas inhabited by small, isolated sheep herds that are experiencing heavy predation losses, which could threaten population viability of the herd.

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EDITOR: Gary Patton, USDA Forest Service, Rocky Mountain Region

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Introduction

This conservation assessment is one of many being produced to support the Species Conservation Project for the USDA Forest Service (USFS), Rocky Mountain Region (Region 2). The bighorn sheep is the focus of an assessment in part because it is a Management Indicator Species (MIS) on several forests in Region 2. More importantly, however, are the crucial implications of an incompatability of active livestock grazing programs and bighorn sheep conservation on National Forest System lands. This assessment addresses the biology of bighorn sheep throughout its range, with emphasis on Region 2 (**Figure 1**). The broad nature of the assessment leads to some constraints on the specificity of information for particular locales. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal

Species conservation assessments produced for the Species Conservation Project are designed to provide land managers, biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of target species based on current scientific knowledge. Assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussions of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to prescribe management direction. Instead, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that result from management (i.e., management implications) that managers will use to guide land management decisions. Furthermore, it discusses management approaches used or recommended in western states and provinces.

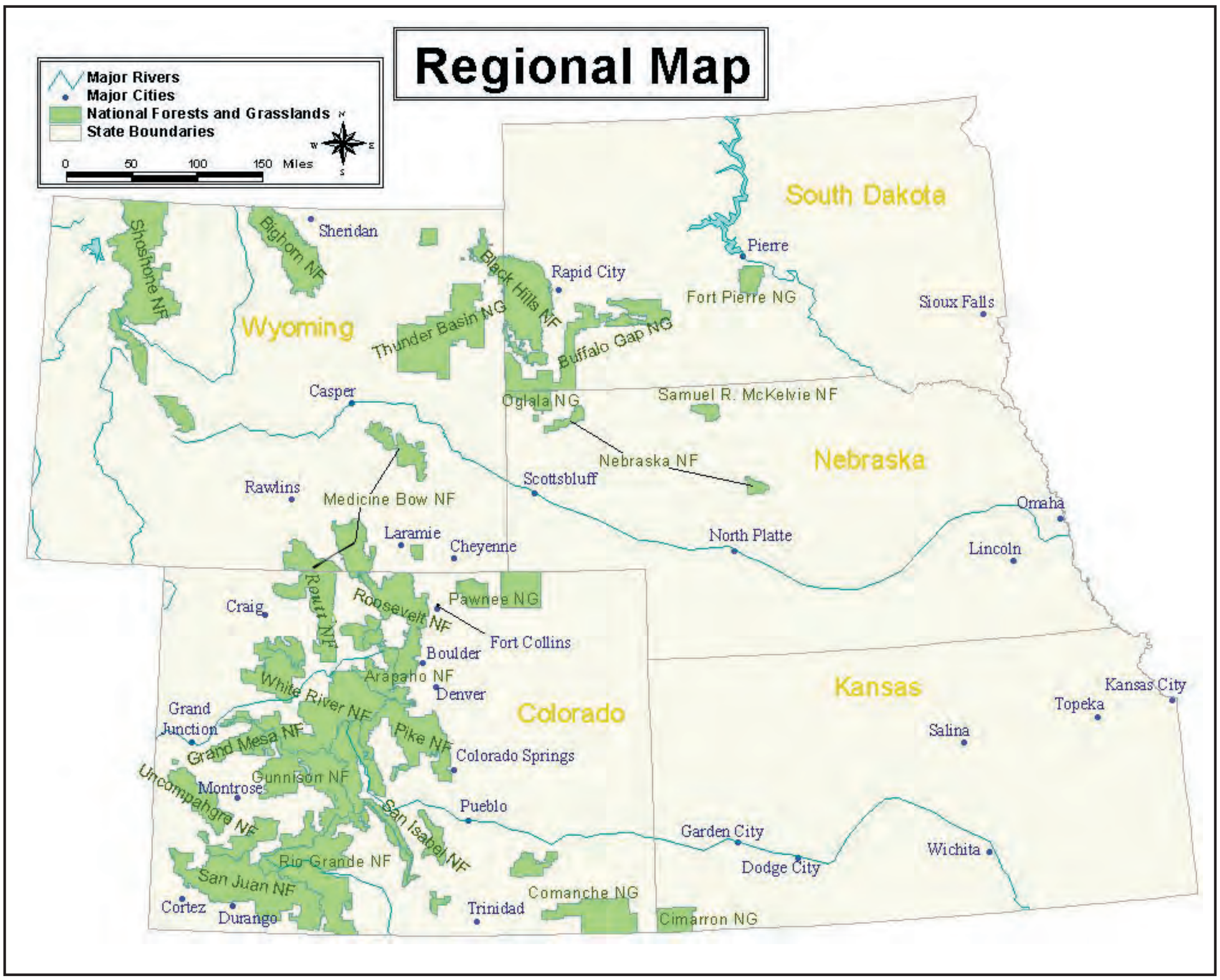

Figure 1. Boundaries of lands administered by USDA Forest Service Region 2.

Scope

This conservation assessment examines the biology, ecology, conservation status, and management of bighorn sheep, with specific reference to the geographic and ecological characteristics of Region 2. Although a majority of the literature on this species originates from field investigations outside the region, this document places that literature in the ecological and social contexts of the central Rocky Mountains. Similarly, this assessment is concerned with characteristics of bighorn sheep in the context of the current environment. The evolutionary environment of the species is considered in conducting the synthesis, but it is placed in a current context.

In producing this assessment, we reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. Not all publications on bighorn sheep are referenced in the assessment, nor were all published materials considered equally reliable. The volume of published reference material on mountain sheep ecology is very large, and it was physically impossible to review all the documents. However, several recent volumes (Toweill and Geist 1999, Valdez and Krausman 1999, Krausman and Bowyer 2003) synthesize much of the published information on both thinhorn and bighorn species of mountain sheep and were very useful in preparing this assessment. The assessment emphasizes refereed literature because this is the accepted standard in science. Non-refereed publications or reports were regarded with greater skepticism, but they were used when refereed information was unavailable. Unpublished data (e.g., Natural Heritage Program records) were important in estimating the geographic distribution of this species, but these data required special attention because of the diversity of persons and methods used to collect the data.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct critical experiments in the ecological sciences, and often observations, inference, good thinking, and models must be relied upon to guide the understanding of ecological relationships (Chamberlain 1897, Hilborn and Mangel 1997).

In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate. While well-executed experiments represent an optimal approach to developing knowledge, alternative approaches such as modeling, critical assessment of observations, and inference were accepted as sound approaches to understanding bighorn sheep. Although the published material on mountain sheep is quite extensive and covers most facets of their ecology, new technologies have only recently become available to address uncertainties regarding genetic variability and long-term persistence for small, isolated bighorn populations.

Publication of Assessment on the World Wide Web

To facilitate their use, these conservation assessments are being published on the USFS Region 2 World Wide Web site. Placing the documents on the Web makes them available to agency biologists, managers, and the public more rapidly than publishing them as reports. More important, it facilitates their updating and ultimate revision, which will be accomplished based on protocols established by USFS Region 2.

Peer Review

In keeping with the standards of scientific publication, assessments developed for the Species Conservation Project have been externally peer reviewed prior to their release on the Web. This assessment was reviewed through a process administered by the Society for Conservation Biology, which chose two recognized experts (on this or related taxa) to provide critical input on the manuscript. It also received review by two state bighorn sheep experts.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) are distributed throughout the mountainous regions of western North America from British Columbia and Alberta south to northern New Mexico and central Arizona. Although bighorn sheep numbers declined dramatically with the settling of the West and are currently at less than 10 percent of historic numbers, they are still considered somewhat secure throughout much of their range (NatureServe 2003). Bighorn sheep populations in Colorado, Wyoming, and South Dakota are classified as secure (NatureServe 2003). The reality, however, is that many regional sheep herds are vulnerable because they consist of small numbers (often less than 100 animals while many biologists consider herds with less than 200 animals at risk due to extrinsic factors), are isolated from adjacent sheep populations (sometimes by large expanses of unsuitable habitat), and because many are threatened by disease transmitted from domestic livestock (Berger 1990, Krausman et al. 1993, Goodson 1994, Wehausen 1999).

Wyoming has 17 herd units (**Figure 2**), nine of which contain over 200 sheep and are considered "relatively secure" (Hurley personal communication 2004). The remaining herd units are comprised of less than 200 individuals each, and they continue to struggle to maintain or increase their numbers due to severe weather, fire suppression, human encroachment, and disease outbreaks (Toweill and Geist 1999).

Colorado has the largest number of bighorn sheep in the United States (**Figure 3**), almost 7,200 in 75 herd units. As in Wyoming, some of the larger herd units are relatively secure while smaller herds remain vulnerable (Toweill and Geist 1999). Although it has not been confirmed that desert bighorns existed in Colorado prior to European settlement, because suitable habitat does exist in western canyon lands contiguous to occupied habitat in Utah, it is probable that desert bighorns did occur historically in far western Colorado but disappeared prior to European settlement. Colorado began transplanting desert bighorns into western Colorado (Black Ridge herd) in 1979. This herd initially increased to over 450 individuals, but it has not continued to increase in numbers or distribution as anticipated and remains vulnerable (Ellenberger personal communication 2004).

South Dakota, Nebraska, and parts of eastern Wyoming historically supported the Audubon (*Ovis canadensis auduboni*) subspecies of bighorn sheep. Unregulated and market hunting, along with severe winters decimated this subspecies, which disappeared in the early 1900's (Toweill and Geist 1999). Present day bighorn sheep herds in both South Dakota and Nebraska are the result of transplants of Rocky Mountain bighorns initiated in 1964 and 1981, respectively (Toweill and Geist 1999, Bourassa 2001). Although bighorn sheep in South Dakota (**Figure 4**) are listed as "apparently secure" (NatureServe 2003), only one of four herd units is large enough (over 150 individuals) to remain genetically viable, without intrusive management efforts to introduce "new" genetic material into individuals herds (Fitzsimmons et al. 1997, Benzon personal communication 2005, Childers personal communication 2005). Nebraska has three bighorn sheep herds (**Figure 5**), two on the Nebraska National Forest (Fort Robinson and Montana herds), containing about 115 sheep, and one on the Cedar Canyon Wildlife Management Area (WMA), with about 65 individuals (Schlichtemeier personal communication 2005). Kansas does not have a wild, free-ranging bighorn sheep population.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

Although the initial decline of bighorns was primarily a result of competition with domestic livestock and exposure to their diseases and parasites, unregulated and market hunting and habitat loss also contributed to declines prior to 1945 (Sugden 1961, Geist 1971, Stelfox 1971, Goodson 1982, Boyce et al. 1990, Valdez and Krausman 1999). With the establishment of wildlife agencies in the western states, bighorn sheep were classified as "Game" animals, and hunting became regulated. In Region 2, all states that support resident bighorn sheep populations (i.e., Colorado, Wyoming, Nebraska, South Dakota) have established, well-regulated hunting seasons for bighorn sheep that restrict the number and, in some cases, the sex of sheep that can be harvested by hunting unit. South Dakota is currently managing their sheep population according to management goals and objectives outlined in their 2000 Rocky Mountain Bighorn Sheep Plan (South Dakota Department of Game, Fish, and Parks 2000). No formalized statewide bighorn management plans currently exist for Rocky Mountain bighorn sheep populations in Wyoming, Colorado, or Nebraska. Wyoming manages by herd unit (Hurley personal communication 2006). Colorado developed a management plan in 1995 for desert bighorn sheep in far western Colorado (Desert Bighorn Sheep Plan 1995). The primary authority and responsibility for habitat management and enhancement for bighorn sheep reside with federal land management agencies (i.e., USFS and Bureau of Land Management, and to a lesser extent the National Park Service and U.S. Fish and Wildlife Service), in cooperation with the state wildlife agencies and state land management agencies on state lands, and American Indian tribes on tribal lands.

Three major statutes govern the land management efforts of federal agencies in the United States, including their responsibilities for conserving bighorn sheep and other wildlife: The Multiple-Use and

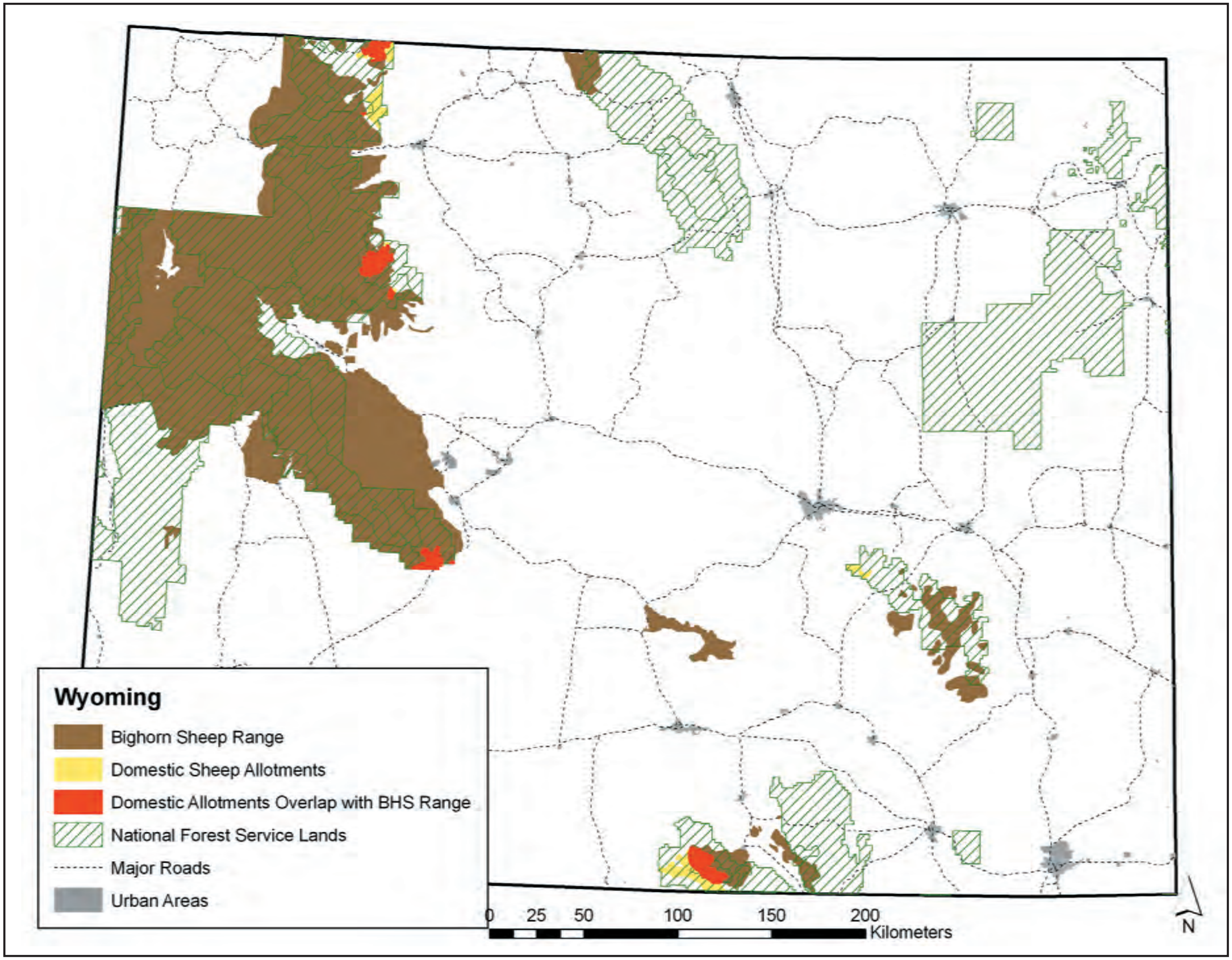

Figure 2. Distribution of Rocky Mountain bighorn sheep in Wyoming. No distinction is made between active and vacant domestic sheep allotments. Because allotment status can change, users are cautioned to validate current allotment status.

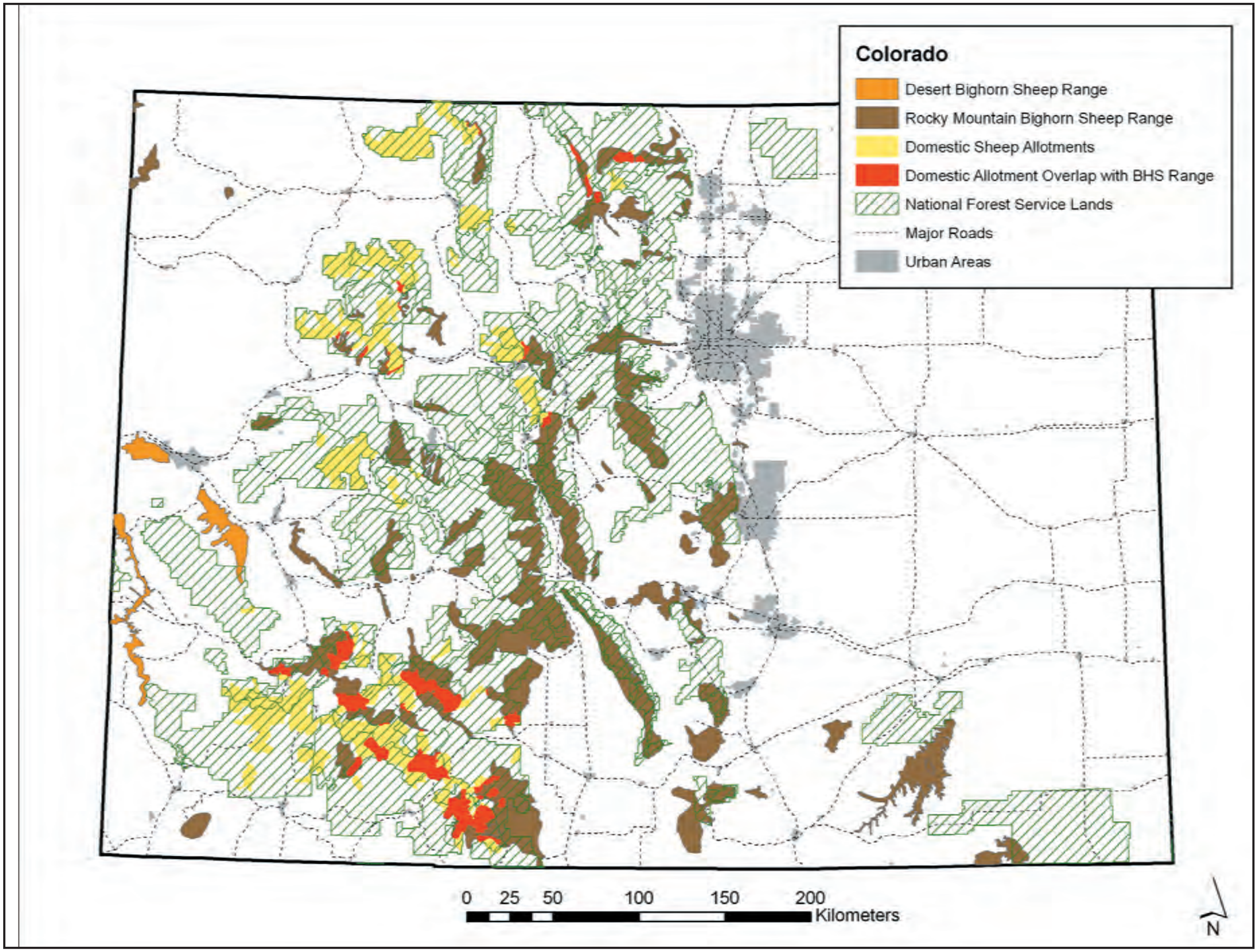

Figure 3. Distribution of Rocky Mountain and desert bighorn sheep in Colorado. No distinction is made between active and vacant domestic sheep allotments. Because allotment status can change, users are cautioned to validate current allotment status.

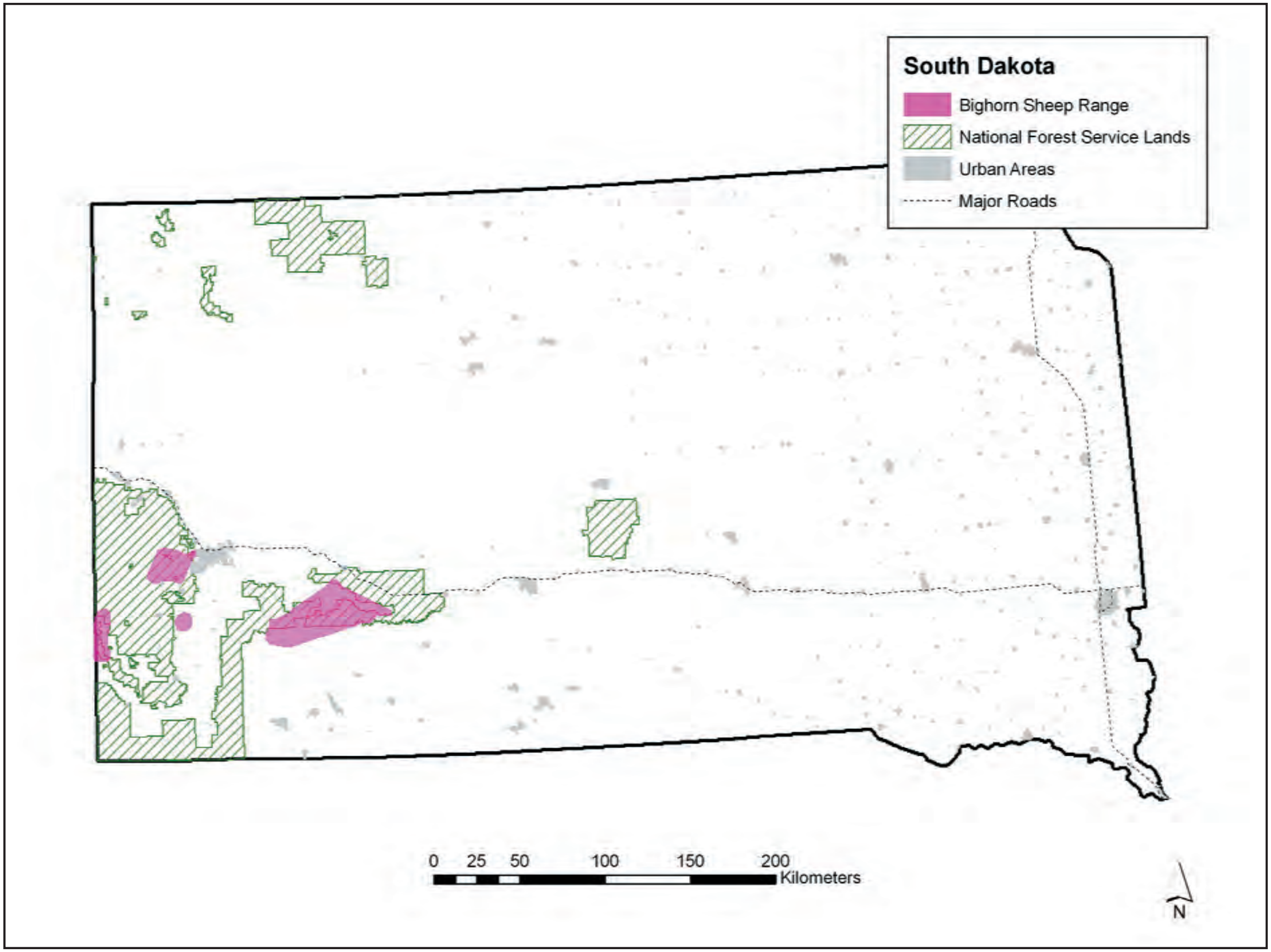

Figure 4. Distribution of Rocky Mountain bighorn sheep in South Dakota. There are no active domestic allotments on Forest Service land in South Dakota.

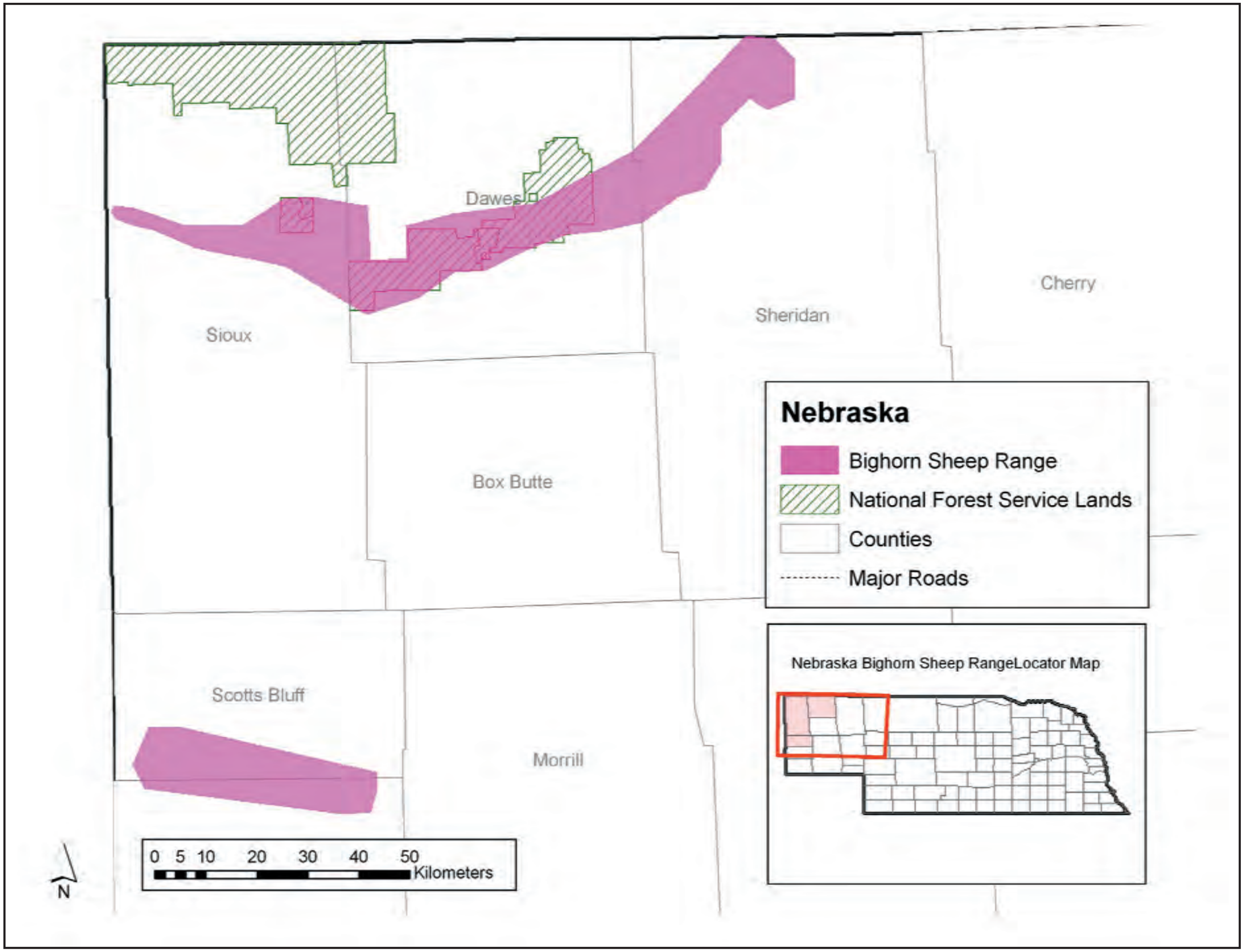

Figure 5. Distribution of Rocky Mountain bighorn sheep in Nebraska. There are no active domestic allotments on Forest Service land in Nebraska.

Sustained Yield Act of 1960, as amended in 1996; the National Environmental Policy Act (NEPA) of 1969, as amended in 1982; and the National Forest Management Act (NFMA), as amended in 1982 and again in 2000. The Multiple-Use and Sustained-Yield Act mandates that the USFS provide for the multiple use of renewable surface resources in a manner that best meets the needs of the American public. It also established wildlife as a primary purpose for which the National Forest System would be managed.

NEPA requires federal agencies to develop interdisciplinary plans for the use of the forest's natural resources, to consider a range of alternatives in the planning process, and to document the impacts of the various alternatives on the natural resources of the forest. A significant aspect of the NEPA planning process is identifying impacts on species listed or proposed for listing under the Endangered Species Act of 1973, and other species of concern as identified at regional or forest levels. Beyond federally listed or proposed species, the categories of species selected for analysis by forests depends on the planning rule under which a forest plan was developed.

NFMA requires the USFS to provide for diversity of plant and animal communities, and the 1982 planning regulations (36 CFR 219.19) implementing NFMA stated that "Fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired non-native vertebrate species in the planning area." The new 2005 planning rule shifts from the concept of species viability to ecosystem sustainability, a framework within which the diversity of plant and animal communities should be provided. Where this approach is inadequate to maintain or restore the conditions necessary to support federally listed species, "species of concern," and "species of interest," plans must contain provisions specific to those species.

The 1982 planning rule established sensitive species and Management Indicator Species (MIS) to help the USFS meet its obligations for maintaining species viability. Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because current or predicted downward trends in abundance, or significant current or predicted downward trends in habitat capability that would reduce its distribution. MIS are intended to represent the status of a larger functional group of species or important habitats. They are monitored to reflect the effects of land management actions on the portion of the ecological system they were selected to represent. Bighorn sheep have been listed as MIS on several Region 2 forests.

Under the new 2005 planning rule, sensitive species and MIS categories may no longer exist. Newly designated categories are "species of concern" and "species of interest." Species of concern are "…those species for which the Responsible Official determines that continued existence is a concern and listing under the Endangered Species Act (ESA) may become necessary." Species of interest are defined as "…those species for which the Responsible Official determines that management actions may be necessary or desirable to achieve ecological or other multiple-use objectives." As forests revise their plans over the next few years, they will transition to the new planning rule. It is likely that bighorn sheep will fall under the species of interest category, but how this status is reflected in forest and region-wide management is unclear as the USFS develops its regulations and policies for implementing the new rule. However, because of the public and economic importance of bighorn sheep, and the crucial implications of livestock grazing programs on federal lands to the future welfare of bighorn sheep populations, it is anticipated that bighorn sheep will continue to be an important focal point for National Forest System management in Region 2.

Other federal laws or executive orders that provide authority to federal agencies to manage plants, fish, and wildlife resources include Agriculture Appropriation Act, Bald Eagle Act, Endangered Species Act, Federal Land Policy and Management Act, Federal Water Pollution Control Act, Fish and Wildlife Coordination Act, Forest and Rangeland Renewable Resources Planning Act, Sikes Act, and Executive Order 11990, Protection of Wetlands. In addition to these federal statutes, the USFS implemented their "FULL CURL" program in the late 1990's, which promotes the protection of bighorn sheep habitat, fosters greater cooperation among governmental entities, landowners, and the general public in support of bighorn sheep conservation, and assists USFS personnel in implementing provisions in individual forest plans regarding bighorn habitat management and enhancement. The "FULL CURL" program aided in the development of a 2001 white paper (authored by Tim Schommer and Melanie Woolever) on domestic sheep-bighorn sheep management titled: A Process for Finding Solutions to the Incompatibility Between Domestic Sheep and Bighorn Sheep. This process paper is sanctioned by the agency and recommended for use in conflict resolution. In the past, the USFS has used

Memoranda of Understanding to work cooperatively with other federal and state agencies to manage domestic and bighorn sheep interactions in California (U.S. Fish and Wildlife Service 2001). In 1992, the BLM established guidelines (BLM, Instruction Memorandum 92-264) for managing domestic sheep in bighorn sheep habitats to prevent contact between domestic and bighorn sheep. Those guidelines were revised in 1998.

Biology and Ecology

Systematics and description

Mountain sheep are in the order Artiodactyla, family Bovidae, and genus *Ovis*. Presently, there is little consensus regarding the number of species in the genus *Ovis* (Toweill and Geist 1999, Krausman and Bowyer 2003). Wild sheep are generally divided into three basic forms based on their body conformation and habitat preferences: moufloniforms, which include the European (*O. musimom*) and Asiatic (*O. gmelinii* and *O. vignei*) mouflons; the argaliform, which consists of the central Asian argali sheep (*O. ammon*); and the pachyceriforms, which include the Siberian snow sheep (*O. nivicola*) and the North American wild sheep (*O. dalli* and *O. canadensis*) (Valdez and Krausman 1999).

Krausman and Bowyer (2003) list seven subspecies of bighorn sheep in North America, but they state that when new DNA information regarding their genetics becomes available, it is unlikely that all seven subspecies will continue to be recognized (Jessup and Ramey 1995, Wehausen and Ramey 2000). Historically, the classification of mountain sheep into distinct subspecies was based on subjective assessment of biogeographic differences in morphology of their skulls and horns. Cowan (1940) was the first zoologist to attempt to classify bighorn sheep at the subspecies level (Ramey 2000), and his work remained the standard for bighorn sheep classification until new statistical methods and DNA analyses were brought to bear on the topic (Ramey 2000). Recent analyses of anatomical and mitochondrial DNA (mtDNA) data suggest that *Ovis canadensis auduboni* and *O. c. canadensis* should be synomized, and populations of *O. c. californiana* in British Columbia, Washington, Oregon, and southwestern Idaho are not different from *O. c. canadensis* (Wehausen and Ramey 2000). However, populations of *O. c. californiana* from the central and southern Sierra Nevada possessed a unique DNA-haplotype from *O. c. sierraensis* populations in the northern Sierra Nevada (Wehausen 1991, Ramey 1993, Ramey 1995, Boyce et al. 1997). An analysis of morphological data from desert bighorn sheep did not support separating them into four separate subspecies (Ramey 1993, Wehausen and Ramey 1993). Ramey (1995) came to the same conclusion after examining mtDNA haplotypes for the four subspecies of desert bighorns and suggested they represented one polytypic subspecies, *O. c. nelsoni* Merriam 1897.

No biogeographic barriers apparently existed in western North America prior to human settlement, which suggests that Rocky Mountain and desert bighorn sheep may have exhibited clinal variation in many phenotypic attributes (Valdez and Krausman 1999). Recent mtDNA data for *Ovis canadensis canadensis* also suggest that no biogeographic barriers prevented gene flow on a regional scale in the past. However, it is important to note that recent mtDNA haplotype frequencies among bighorn sheep herds indicate that little gene flow is presently occurring among populations (Luikart and Allendorph 1996).

Members of the genus *Ovis* are characterized by the presence of interdigital, inguinal, and preorbital glands, and the absence of subcaudal glands and a chin beard (Valdez and Krausman 1999). Bighorn sheep are stocky animals whose pelage color varies seasonally and geographically from almost white to dark brown, with a dorsal midline of darker hair (Krausman and Bowyer 2003). The muzzle, rump patch, and back of their legs are generally white in color. Adult males weigh up to 137 kg (average 79 kg) and adult females weigh an average of 59 kg; lambs weigh 2.8 to 5.5 kg at birth (Shackleton et al. 1999). Adult male and female desert bighorns weigh slightly less, averaging 68 and 52 kg, respectively (Valdez and Krausman 1999). Adult male bighorn measurements (mm) are: total length, 1321 to 1956; tail, 102 to 152; shoulder height, 813 to 1118. Measurements for adult females are: total length, 1168 to 1880; tail, 102 to 127; shoulder height, 76 to 91 (Valdez and Krausman 1999). North American sheep have 32 teeth, with a dental formula of I 0/3, C 0/1, P 3/3, M 3/3. The deciduous teeth all erupt within the first week of life while permanent dentition is not complete until 4 years of age (Krausman and Bowyer 2003).

The most defining characteristic of bighorn sheep is the large horns of adult males, which may constitute 8 to 12 percent of their total body mass (Geist 1966). Generally, the horns of desert bighorn sheep flare more widely than those of Rocky Mountain bighorns do, but not as much as those of thinhorn sheep. The horns of female bighorn sheep have less mass, are shorter than those of males are, and are relatively thin and gently curved backwards. In contrast, the massive horns of males sweep out, back, and downward to form a full circle, or curl, at maturity (Krausman and Bowyer 2003). The horn core of bighorn sheep is a highly vascularized bony structure. Wehausen and Ramey (1993, 2000) described a clinal relationship in mean core volume wherein northern sheep have smaller core volumes than sheep living in southern parts of their range. They hypothesized that the larger horn core volumes functioned to dissipate heat in hot environments.

Bighorn sheep horn growth patterns can be very useful to biologists for estimating an animal's age (Krausman and Bowyer 2003), as horn growth is greater during the summer months, producing an alternating pattern of annual growth rings. Biologists are, however, cautious in trying to determine exact age of older animals from annual growth rings because horn tips are often "broomed" (broken during clashes with other males) back in older males, obscuring lamb and yearling growth rings (Shackleton and Hutton 1971).

Because horn growth patterns are generally consistent among sheep populations, they also can be useful to wildlife managers for evaluating population status (Krausman and Bowyer 2003). Low-density populations in good habitat experience greater horn sheath growth than populations at or near carrying capacity. Good annual horn sheath growth, particularly for yearling and 2-year-old rams, can be indicative of a fast-growing, highly productive sheep herd.

Distribution and abundance

Wild sheep are one of the most widely distributed ungulates in the world (Valdez and Krausman 1999). Cowan (1940) proposed that North American sheep evolved in the Beringian region and migrated into North America during the early Pleistocene era, becoming isolated from their Asiatic ancestors when large glacial masses melted and flooded the Bering land bridge connecting Asia to North America (Geist 1985). Recent fossil discoveries support Cowan's hypothesis (Stokes and Condie 1961, Guthrie 1968, Stock and Stokes 1969). Bighorn sheep probably moved southward during the Sangamon Period and eventually spread from southern California into Wyoming (Martin and Gilbert 1978, Wang 1984). The first evidence of wild sheep in Region 2 was found in Wyoming's Trap Cave site in north-central Wyoming (Wang 1988). These sheep remains dated back over 100,000 years. However, evidence of bighorn sheep in this area disappeared during the Wisconsin glacial period and did not reappear until deglaciation began tens of thousand of years later (Toweill and Geist 1999). Isolation of the pachyceriforms during the Wisconsin glaciation probably led to the development of modern forms of Rocky Mountain and desert bighorn sheep (Geist 1985a, b, 1987, Pielou 1991, Geist 1999).

Deglaciation created extensive montane and grassland habitats for mountain sheep and allowed them to spread throughout most of western North America. Seton (1929) estimated mountain sheep numbers at approximately two million in the contiguous United States and another two million in Canada and Alaska during pristine times. However, Valdez (1988) was not convinced that mountain sheep were uniformly distributed across montane habitats in western North America, and suggested that wild sheep numbers probably did not exceed 500,000. In Alaska, where wild sheep still occupy much of their historical habitats, sheep numbers do not exceed 74,000 (Nichols 1975, Valdez and Krausman 1999).

Prior to the arrival of Europeans in western North America, Rocky Mountain bighorn sheep occupied the mountains and river canyons as far north as southern British Columbia and southwestern Alberta (55° N), south through the Rocky Mountains into northern New Mexico (36° N), and east into the badlands of North Dakota, and the Black Hills of South Dakota and Nebraska. Desert bighorns, adapted to hot, dry environments, were found from southern Nevada and Utah (below 40° N), perhaps far western Colorado, south to Baja California (24° N) and east through Arizona, southern New Mexico, and west Texas (Monson 1980).

Throughout its range, the distribution of bighorn sheep is naturally fragmented due to the patchy nature of their preferred habitat (Valdez and Krausman 1999). This made bighorn sheep vulnerable to the effects of unregulated hunting and the transmission of disease from domestic sheep introduced in the mid-19th century. The results were large die-offs and the extirpation of many herds (Valdez and Krausman 1999). The number of domestic sheep grazing the 11 western states rose to almost 28 million by 1920, and their numbers remained high until 1945 (Goodson 1982). At the same time, bighorn numbers declined dramatically from approximately 500,000 pre-1800 (Valdez 1988) to only 15,000 to 20,000 in 1960 (Buechner 1960).

After 1945, the domestic sheep industry in the United States declined. The reduction in domestic sheep numbers, combined with active bighorn sheep transplant and habitat enhancement programs, resulted in significant increases in bighorn numbers (Buechner

1960). Bighorn sheep populations have continued to increase in numbers and distribution throughout western North America to the present (Valdez and Krausman 1999). By the end of the 20th century, Toweill and Geist (1999) estimated that there were approximately 67,500 bighorn sheep in North America: 31,500 to 34,500 Rocky Mountain bighorns, 10,500 California bighorns, and 22,500 desert bighorns.

Within Region 2, the estimated number of Rocky Mountain bighorns varies considerably from state to state. Colorado estimates they have about 7,200; Wyoming has approximately 6,000; South Dakota has less than 500; and Nebraska has less than 200 (**Table 1**). A small population of desert bighorns, now numbering almost 500 individuals, was established in western Colorado in 1979 (Wolf 1990). No California bighorn sheep herds occur within Region 2 (Toweill and Geist 1999).

Population trend

Throughout much of western Canada, the western United States, and northern Mexico, bighorn sheep abundance and distribution declined precipitously in the 19th century due to human impacts (Bailey 1980, Hansen 1980b). The Audubon subspecies (if DNA technology demonstrates that it actually existed as a valid subspecies) was extirpated in the early 1900's from eastern Montana, eastern Wyoming, western North and South Dakota, and from northwestern Nebraska. Rocky Mountain and California bighorns suffered the same fate in Washington, Oregon, northern California, Nevada, and New Mexico, and desert bighorns disappeared from western Texas and some states in Mexico (Valdez and Krausman 1999). Factors associated with bighorn sheep declines included overgrazing by and competition with domestic sheep and cattle in the 1800's; introduction of domestic sheep diseases; unregulated hunting, including market hunting; habitat loss; competition from mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*); disturbance from mining, logging, oil and gas exploration, road construction, and other human related causes (Geist 1971, Gallizioli 1977, Leslie 1977, Hamilton et al. 1982, Krausman et al. 1989, Harris 1992, Holechek et al. 1995, Valdez and Krausman 1999).

Bighorn sheep populations declined to less than 25,000 individuals in the continental United States by 1960 (Buechner 1960, Valdez and Krausman 1999, Toweill and Geist 1999). However, transplant programs initiated in Canada, the United States, and Mexico were successful in restoring bighorn sheep to over 200 historic sites by 1990 (Bailey and Klein 1997). Valdez and Krausman (1999) estimated there were more than 185,000 wild sheep in North America by 1991. Shackleton et al. (1999) reported 101,400 to 127,300 thinhorn sheep in Canada and Alaska and 64,500 to 67,500 bighorn sheep in Canada, the United States, and Mexico. Although bighorn sheep numbers and distribution have increased dramatically since 1960 due to transplant and habitat conservation efforts, many individual herds remain small (less than 150 individuals) and susceptible to extirpation (Berger 1990, Fitzsimmons and Buskirk 1992, Krausman et al. 1993).

Within Region 2, bighorn sheep populations increased steadily from the 1960's until 2003. They have since stabilized or decreased slightly in Colorado and Wyoming while in South Dakota and Nebraska, active transplant programs continue to result in slight increases in total sheep numbers and distribution, although some populations in these states have not grown significantly in the last few years. A number of wild sheep herds in Region 2 are small, stagnant, and susceptible to extirpation. Although many domestic sheep allotments on national forests in the Region 2 have been abandoned or converted to cattle use, many remain active, and most bighorn herds within the Region have been exposed to disease pathogens in the past. Consequently, many herds remain vulnerable to disease.

Table 1. Population estimates for Rocky Mountain bighorn sheep in USDA Forest Service Region 2. Estimates are from Buechner (1960), Trefethen (1975), Thorn et al. (1985), Valdez and Krausman (1999), Toweill and Geist (1999) personal communication with state and federal biologists – CO: B. Watkins; NE: G. Schlichtemeier; SD: T. Benzon, E. Childers (NPS); WY: K. Hurley (2005).

State	1960	1975	1985	1991	1998	2003	2005
Colorado	2,500 - 3,200	No estimate	6,045	6,300	6,995	7,400	7,175
Nebraska	0	0	12	No estimate	57	194	178
S. Dakota	22	150	165	380	375	428 - 484	415
Wyoming	1,800 -2,000	4,500	6,305	6,550	6,725	6,065	6,172
TOTALS	**4,322 – 5,222**	**>4,650**	**12,527**	**13,230**	**14,152**	**14115**	**13,940**

By far, the largest amount of bighorn habitat and total sheep are found in Colorado (7,175) and Wyoming (6,172). However, only half of Wyoming's herds and 10 of 73 herds in Colorado have more than 200 individuals. South Dakota has four widely separated herds (three in the Black Hills National Forest and one in Badlands National Park); one of these (Spring Creek) has more than 200 individuals while the remaining three are small (less than 90) and two of those have experienced die-offs in the last 10 years. Nebraska currently has three small herds of bighorns. The Fort Robinson herd in the northwest corner of the state is the oldest herd in the state. It had about 150 animals until a disease epizootic reduced its number by half in 2004-2005; it now consists of about 60 bighorns. The two remaining herds in Nebraska have a similar number of bighorns. All three bighorn herds in Nebraska are located near domestic sheep and are considered vulnerable to a disease event. The desert bighorn sheep herds located in western Colorado remain above the threshold for minimum population viability, but they have not been increasing in the last few years (Ellenberger personal communication 2004).

Movement and activity patterns

Bighorn sheep habitat in western North America is naturally fragmented within a much larger landscape, resulting in many populations that are comparatively small, often consisting of less than 150 individuals. The fragmented nature of sheep habitat and the relatively small size of most bighorn herds suggest that bighorns evolved with a meta-population structure where small populations would not persist without movement and reproduction among herds (Gilpin and Hanski 1989, Berger 1990, Bleich et al. 1990b). In the absence of intrusive management programs, dispersal corridors that connect these fragmented habitats and their subpopulations into a metapopulation structure are critical to maintaining viable populations of sheep.

The presence of dispersal corridors between suitable patches of habitat, and the ability and propensity for sheep to move between patches, influences their ability to disperse into suitable, but unoccupied habitats (Noss 1987, Simberloff and Cox 1987, Hudson 1991, Douglas and Leslie 1999). Although there are few studies addressing bighorn sheep dispersal behavior, their dispersal rates are believed to be low (Shackleton et al. 1999). Immigration and emigration are relatively insignificant in most bighorn populations because of high range fidelity (Geist 1971, Festa-Bianchet 1991a, Jorgenson et al. 1997). However, newly established (transplanted) populations occupying high quality habitats are prone to disperse (Butts 1980, Geist 1999). Bighorns occupying high quality habitats at low density have faster growth rates, breed at an earlier age, have higher fecundity, and live shorter lives than sheep living in areas where forage resources are in short supply (Geist 1999, Toweill and Geist 1999). This appears to be an adaptive mechanism to variable habitat quality in which intraspecific competition may become a factor influencing the tendency of sheep to disperse (Geist 1999, Toweill and Geist 1999). Movements of Rocky Mountain bighorn sheep between isolated mountain ranges are not common while movements of desert bighorn sheep from range to range are more frequent (Bleich et al. 1990b, Jager 1994).

Many bighorn sheep populations migrate between seasonal ranges. Although some populations in mountainous areas of western North America may move up to 70 km seasonally, most such movements involve much shorter elevational shifts driven by behavioral, physiological, or environmental factors (Smith 1954, Berwick 1968, Spaulding and Mitchell 1970, Geist 1971, Hebert 1973, Festa-Bianchet 1986a, b, Hengel et al. 1992, Krausman and Bowyer 2003). The movement of Dall sheep between seasonal ranges is related to plant phenology, temperature, and snow depth (Hoefs and Cowan 1979). Many Rocky Mountain and California bighorn sheep populations also use seasonal ranges, and movement between them is likely based on the same factors. The general pattern of seasonal migrations is for sheep to move to higher elevations in May or June following plant phenology to take advantage of high quality, highly digestible new vegetative growth (Berwick 1968, Geist 1971, Oldemeyer et al. 1971, Becker et al. 1978). During the lambing season, adult female sheep may deviate from this pattern and move to areas that provide more security from predators (Festa-Bianchet 1988c, Berger 1991, Bleich et al. 1997, Etchberger and Krausman 1999). Bighorn sheep migrate to lower elevation winter ranges in October and November (Woolf et al. 1970, Geist 1971, Becker et al. 1978). Rocky Mountain bighorn sheep on winter range are also known to move to high-elevation, wind-swept ridges in response to heavy snow accumulations at lower elevations (Nichols and Erickson 1969, Geist 1971, Geist and Petocz 1977). Desert bighorn sheep are also known to use distinct spring, summer, and fall-winter ranges (Eustis 1962, Geist 1971, Bates et al. 1976, King and Workman 1982, Elenowitz 1983, Krausman et al. 1989) based primarily on the distribution of seasonal rainfall and forage conditions.

Bighorn sheep are not territorial (Lawson and Johnson 1982) but occupy season-specific home ranges. Except during the breeding season, when the distributions of both sexes overlap for 2 to 3 weeks, adult males and females accompanied by young of the year and yearlings largely remain in separate groups, but they may share the same winter range (Blood 1963, Woolf et al. 1970, Geist 1971, Geist and Petocz 1977, Lawson and Johnson 1982, Bleich et al. 1997). Young sheep learn home ranges by following older animals; home ranges are typically well established by the time the animals are four years old (Geist 1967, 1971). Adult female sheep display greater home range fidelity than males do (Festa-Bianchet 1986a, b). Bighorn sheep home range size is usually smallest in winter when forage is scarce or low in quality, but desert bighorns occupy smaller home ranges in summer when they remain close to watering holes (Jones et al. 1957). Daily movements of mountain sheep range from 3 to 16 km and are influenced by forage conditions and weather patterns (Welles and Welles 1961, Blood 1963, Woolf et al. 1970, Stelfox 1976).

Mountain sheep are generally diurnal, and activity patterns involve alternating feeding and resting bouts throughout the day (Augsburger 1970, Geist 1971, Seip and Bunnell 1985a). However, Woolf et al. (1970) reported that bighorn sheep in Yellowstone National Park fed long after sunset in response to heavy tourist activity. Daily feeding and resting bouts are not synchronous within or between groups of sheep (Jones 1959, Todd 1972). The number of daily feeding periods varies and is highest in summer. Feeding activity is lowest during the winter and is influenced by winter severity and forage quality and quantity. The proportion of time spent feeding appears to be shortest in areas where forage quantity and quality were greatest, but it was also influenced by day length and thermal stresses (Welles and Welles 1961, Van Dyke 1978, Eccles 1983). Van Dyke (1978) observed that females spent more time feeding than males did, possibly due to the physiological demands of lactation. Eccles and Shackleton (1986) found no significant differences in feeding patterns based on social class, but they did report that females in poor condition fed longer in the fall and spent more time resting in the winter than their healthy counterparts.

Habitat

Bighorn sheep are adapted to a wide variety of habitats across western North America (Lawson and Johnson 1982), ranging in elevation form sea level to over 4,300 m (Buechner 1960, Welles and Welles 1961, McCullough and Schneegas 1966, Stelfox and Tabor 1969, Oldemeyer et al. 1971, Shackleton et al. 1999, Vitt 2005d). The climate across bighorn sheep range varies widely, but it generally can be described as semi-arid to arid. Precipitation varies from 20 to over 40 cm each year (Smith 1954, Jones 1959, Shallenberger 1966, Hansen 1980a, Sandoval 1980). Succulent vegetation in summer and snow and ice in winter help wild sheep to survive for long periods without freestanding water (McCann 1956, Kornet 1978, Van Dyke 1978).

Records indicate that historically, bighorn sheep were sometimes found distant from rugged mountainous terrain (Cowan 1940, Smith 1954, Wishart 1958). However, their current distribution is confined to scattered populations in open or semi-open, often precipitous, terrain characterized by a mix of steep or gentle slopes, broken cliffs, rock outcrops, and canyons and their adjacent river benches and mesa tops (Buechner 1960, Sugden 1961, Wilson 1968, Welch 1969, Drewek 1970, Geist 1971, Merritt 1974, Stelfox 1975, Clark 1978, Adams et al. 1982, Holl and Bleich 1983, Risenhoover and Bailey 1985, Etchberger et al. 1989, Bailey and Klein 1997, Shackleton et al. 1999). Slope steepness appears to be a significant feature of Rocky Mountain and California bighorn sheep habitat. Rocky Mountain bighorns use slopes of 36 to 80 percent in Montana and Colorado, while avoiding slopes less than 20 percent (Frisina 1974, Pallister 1974, Fairbanks et al. 1987). California bighorns use slopes ranging from 6 to 100 percent in Oregon (Van Dyke 1978).

Bighorn sheep are primarily animals of open habitats, such as alpine meadows, open grasslands, shrub-steppe, talus slopes, rock outcrops, and cliffs; in some places, however, they may use areas of deciduous and conifer forests, especially where openings may have been created by clear-cuts or fire (Blood 1961, Demarchi 1965, Erickson 1972, Pallister 1974, Goodson 1978, Kornet 1978, Van Dyke 1978, Hansen 1982, Risenhoover and Bailey 1985, Dale 1987). Densely forested areas provide little forage and poor visibility and are rarely used by bighorn sheep, except for shade in summer, escape from insects, and protection from high winds on very cold days (McCann 1956, Geist 1971, Wikeem 1984, Cook 1990). Open forests, however, are used in some areas for foraging and thermal cover (Spaulding and Bone 1970, Demarchi and Mitchell 1973, Pallister 1974, Jorgenson and Turner 1975, Goodson 1978, Kovach 1979, Shackleton et al. 1999).

Visibility is an important habitat variable for bighorn sheep, so much so that the structure and height of vegetation are probably more important than composition of plant species because high visibility facilitates the detection of predators (Risenhoover and

Bailey 1985, Wakelyn 1987). Desert bighorn sheep have abandoned traditional home ranges because fire suppression allowed vegetation to grow and obstruct visibility (Etchberger et al. 1989, Krausman et al. 1989, Etchberger et al. 1990). Deforge (1980) observed that reduced visibility in maturing chaparral lowered the suitability of this habitat for desert bighorns, resulting in decreased carrying capacity and eventual loss of bighorn range. Fire is an important tool available to land managers for producing and maintaining sub-climax grassland and parkland habitats that provide greater visibility for bighorn sheep (Geist 1971, Erickson 1972, Arnett 1990).

Climate, elevation, and latitude influence the vegetative structure and composition in bighorn sheep habitat (Demarchi 1965, Todd 1972, Risenhoover and Bailey 1985, Dale 1987, Krausman et al. 1989, Bleich et al. 1997). Within individual home ranges, different habitats meet the specific requirements of wild sheep, including foraging, resting, mating, lambing, thermal cover, and predator avoidance (Hansen 1982, Risenhoover and Bailey 1985, Dale 1987). Seasonal use of different slopes and aspects results in a mosaic of plant communities and phenological patterns which provide foraging and security opportunities for bighorn sheep (Valdez and Krausman 1999).

Warm temperatures on south-facing slopes result in earlier green-up, marking the transition from winter range to spring range (Hudson 1976, Stelfox 1976). During the spring green-up, mineral licks appear to be an important component of bighorn sheep habitats where soils are derived from granitic materials. As temperatures continue to rise during late spring and early summer, bighorn sheep make greater use of north, east, and west-facing slopes at higher elevations for foraging (Smith 1954, McCullough and Schneegas 1966, Stelfox 1975, Goodson 1978). Alpine meadows and high elevation plateaus are important summer foraging areas for many Rocky Mountain sheep populations (Blood 1961, Sugden 1961, Pallister 1974, Shannon et al. 1975). The elevation and aspect preferred by bighorn sheep varies according to forage succulence and ambient temperature (Stelfox 1975).

While bighorns feed in open areas, they are rarely found more than 400 m from escape cover, where they have an advantage over most predators (Oldemeyer et al. 1971, Erickson 1972, Pallister 1974, Krausman and Leopold 1986, Krausman and Bowyer 2003). Talus slopes, rock outcrops, and cliffs provide habitat for resting, lambing, and escape cover (Erickson 1972, Kornet 1978, Van Dyke 1978). Adult male sheep are known to move farther away from security cover than females, presumably because of a combination of factors including exclusion from some habitats by adult ewes and lambs, selection for optimal forage to maximize their growth rate, and greater ability to defend themselves from predators (Shank 1979, Hansen 1982).

Escape terrain is critical for ewes during lambing (Blood 1961, Kornet 1978, Hall 1981), to the extent that they will sacrifice access to high quality forage for security (Festa-Bianchet 1989a, Cook 1990, Bleich et al. 1997). Both ewes and lambs are vulnerable to predation immediately prior to and for 1 to 2 days after parturition (Shackleton and Haywood 1985). Shackleton et al. (1999) suggested that bighorn lambing habitat served three primary functions: 1) escape cover from predators, 2) a favorable microsite that afforded lambs protection from bad weather, and 3) a secure, secluded area where the ewe and lamb could cement the mother/young bond. Rachlow and Bowyer (1998) indicated that several variables were useful in discriminating Dall sheep lambing sites in Alaska; these included distance to escape cover, cover of grasses, slope aspect, brokenness, steepness, and the presence of snow. Although there are exceptions, bighorns in the Rocky Mountains often lamb on or very near their winter ranges in steep, rugged terrain (Geist 1971, Horejsi 1976, Becker et al. 1978, Smith et al. 1991). Adult female bighorns exhibit strong fidelity to parturition sites and often use the same lambing grounds year after year (Geist 1971, Becker et al. 1978, Etchberger and Krausman 1999).

Key elements of winter ranges for bighorn sheep include low snow depth and wind-swept areas with sufficient forage and adjacent escape terrain for eluding predators (Krausman and Bowyer 2003). Wind, cold temperatures, and heavy snow accumulation are likely limiting factors for Rocky Mountain bighorn sheep in some areas. Slopes with snow accumulation in excess of 30 cm increased the metabolic cost of foraging and travel for thinhorn sheep, and were generally avoided (Hoefs and Cowan 1979, Seip and Bunnell 1985b, Nichols 1988). Stelfox (1975) suggested that the critical snow depth for Rocky Mountain bighorn lambs was 30 to 44 cm, 32 to 48 cm for yearlings and adult females, and 36 to 54 cm for adult males. Consequently, most bighorn winter ranges occur on steep south, southwest, or southeast-facing slopes where maximum heat gain reduces cold stress and snow cover, and increases the availability of forage (Smith 1954, Blood 1961, McCullough and Schneegas 1966, Stelfox and Tabor 1969, Morgan 1970, Geist 1971, Riggs 1977, Krausman and Bowyer 2003). In some areas, bighorn sheep may remain at or move to high elevation, wind-swept ridges to avoid heavy snow depths at lower elevations (Nichols and Erickson 1969, Geist 1971, Geist and Petocz 1977). Snow quality (Sugden 1961) and the proximity of security cover (Wishart 1958, Shannon et al. 1975) are other factors influencing sheep use of winter ranges.

Very little is known about the mineral requirements of bighorn sheep. Bighorns commonly use mineral licks through their range in North America (Jorgensen personal communication 2006) and are known to consume relatively large quantities of soil in Wyoming, Colorado, Utah, and Idaho. Dietary deficiencies in sodium, phosphorous, and calcium were thought to be responsible for this behavior, but the reasons remain speculative (Honess and Frost 1942, Packard 1946, Smith 1954, Wilson 1968). Selenium deficiencies are suspected of contributing to pneumonia outbreaks in domestic and wild sheep lambs (Hnlicka et al. 2002), but the relationship is not clear. Rock et al. (2001) reported that the immune system was apparently the first physiological function affected by low selenium levels in pregnant domestic ewes. However, at least two bighorn sheep herds in Idaho and Alberta, known to have low average blood selenium levels, have not experienced any pneumonia outbreaks in either adult sheep or lambs (Cassirer personal communication 2004).

Wyoming's Whiskey Mountain bighorn sheep herd was one of the state's most productive herds until 1990, when a pneumonia related die-off occurred. Lamb survival remained very low in the decade following the die-off, and it was hypothesized that mineral deficiencies may have been responsible for low recruitment rates (Anderson 2004). Mioncyzinski (2003) initiated a study to examine relative trace mineral deficiencies in Whiskey Mountain lambs, and concluded that while trace mineral deficiencies may be a periodic problem, they did not appear to be a chronic issue for the herd. Mineral blocks were provided on summer range, but these were not successful in reducing the high lamb mortality (Anderson 2004).

Low lamb survival in mid-summer is not an uncommon mortality pattern following a pneumonia outbreak (Woodard et al. 1972, Spraker 1974, Akenson and Akenson 1992, Cassirer personal communication 2004, Jorgenson *In litt*. July 2006). The high loss of lambs during the mid-summer period in the Whiskey Mountain bighorn sheep herd suggests that pneumonia die-offs could affect bighorn herd demographics for many years after the initial outbreak of the disease, and that trace mineral (selenium) deficiencies may have played a minor role in influencing lamb survival in the decade following the pneumonia die-off (Wyoming Game and Fish Department 2003). Cook (1990) suggested that poor quality summer ranges also influenced mid-summer mortality rates in lambs in Wyoming.

Food and feeding habits

Bighorn sheep occur over a wide range of habitats in western North America, and their diet reflects the availability of forage species across their range (Lawson and Johnson 1982). In general, bighorn sheep forage opportunistically, feeding on palatable plant species that are available seasonally (Sugden 1961, Todd 1975, Browning and Monson 1980, Shackleton et al. 1999). Seasonal forage consumption depends on plant succulence, nutrient quality, and availability (Todd 1975). The breadth of their diet can be extensive within individual populations, ranging from 69 to 88 plant species used over the course of a year (Johnson 1975, Stewart 1975, Hansen 1982, Wikeem and Pitt 1992). Rocky Mountain and California bighorn sheep select forbs most frequently, followed by grasses, and then shrubs.

Forbs are the most palatable forage for bighorn sheep, but they are only available seasonally (Todd 1972). Forbs frequently consumed by bighorns include phlox (*Phlox* spp.), cinquefoils (*Potentilla* spp.), twinflower (*Linnaea americana*), and clover (*Trifolium* spp.) (Constan 1972, Todd 1972, 1975, Stelfox 1976, Thorne 1976). Blood (1967) observed bighorn sheep feeding on both death camas (*Zygadenus venenosus*) and lupine (*Lupinus* spp.) without apparent ill effects. Although forbs contribute the greatest number of species to the diet during the warm months of the year, grasses, based on percent composition, typically dominate bighorn sheep diets (Valdez and Krausman 1999). Common grasses used by sheep include bluegrasses (*Poa* spp.), wheat grasses (*Agropyron* spp.), bromes (*Bromus* spp.), and fescues (*Festuca* spp.). Estes (1979) found that bighorn sheep in Washington preferred bluegrasses and bromes to wheatgrasses and fescues. Browse is more important as a forage class in the fall and winter for some populations (Lawson and Johnson 1982). Browse species used by bighorns include sagebrush (*Artemisia* spp.), willow (*Salix* spp.), rabbitbrush (*Chrysothamnus* spp.), curlleaf mountain mahogany (*Cercocarpus ledifolius*), winterfat (*Eurotia lanata*), bitterbrush (*Purshia* spp.), and green ephedra (*Ephedra* spp.).

Bighorn sheep graze opportunistically rather than selecting for specific plant species. However, marked preferences for individual species are found within all forage classes among sites and seasons (Oldemeyer et al. 1971, Stelfox 1975, Stewart 1975, Wikeem and Pitt 1992). In Montana, Rocky Mountain bighorn diets contained 43 percent big sagebrush, while in British Columbia, big sagebrush made up only one percent of their diet even though it was the most common shrub species available to them (Stewart 1975, Wikeem and Pitt 1992). The differences in observed use of big sagebrush in these areas may be associated with differences in essential oils and palatability between the two sagebrush ecotypes (Plummer 1972).

Plant selection is related to forage availability and the type of habitat used by bighorn sheep (Todd 1972), but weather, snow cover, topography, soil fertility, slope, aspect, and management practices may also influence selection (Valdez and Krausman 1999). Diet quality, indexed by fecal crude protein, increased rapidly during early spring, peaked in June, and began declining to pre-spring levels by October (Cook 1990). A similar pattern was observed for digestible nitrogen and energy (Hansen 1996). Blanchard et al. (2003) reported that bighorn sheep population density was negatively correlated with fecal nitrogen levels, while summer precipitation levels were positively related, suggesting that diet quality declined as population density increased and improved with higher precipitation. Although forage nutrient quality does not correlate well with diet composition (Shackleton et al. 1999), plant cover explained up to 62 percent of all variation in the diet of bighorn sheep (Wikeem and Pitt 1992).

Seasonal variations in the diet of bighorn sheep are reported for many sheep populations. These variations are complicated by age-sex classes of sheep and environmental factors (Smith 1954, Todd 1972, Pallister 1974, Johnson 1975, Bear 1978, Shank 1982, Irwin et al. 1993). Shank (1982) reported that the winter diets of Rocky Mountain bighorn females, lambs, and yearlings were more similar to each other than to the diet of adult males. This was attributed to spatial segregation on their winter range, with different proportions of plant species available. During spring and summer, bighorn sheep feed in areas of green-up to maximize nutrient uptake. The quality of summer forage may be more important in determining lamb survival than the quality of winter forage available to the lambs throughout the winter. Cook et al. (1990) found that summer forage nutrient quality was strongly correlated with winter lamb survival in a low-elevation sheep herd in Wyoming. In desert regions, seasonal use of different forages has been attributed to precipitation patterns and the effects of soil moisture on vegetation classes (Brown et al. 1977, Krausman et al. 1989).

Breeding biology

The breeding season for bighorn sheep extends from late October to early January (Wishart 1958, Buechner 1960), but it usually peaks between mid-November and mid-December for Rocky Mountain bighorn sheep (Honess and Frost 1942, Smith 1954, Sugden 1961, Blood 1963, Geist 1971, Shackleton 1973, Nichols 1978). In contrast, the rut for desert bighorns may last nine months and peak in August and September (Welles and Welles 1961).

The age of maturity for female bighorn sheep is quite variable and dependent upon habitat quality. Ovulation and spermatogenesis begins at about 18 months of age in Rocky Mountain bighorn sheep, but most ewes are 30 months old when they first mate (Woodgerd 1964, Geist 1971, Blunt et al. 1972). In expanding or highly productive sheep herds, ewes have given birth to their first lamb at 12 to 24 months of age (Woodgerd 1964, Shackleton 1973, McCutchen 1976, Van Dyke 1978, Sandoval 1981, Morgart and Krausman 1983). Nichols (1978) reported that 75 percent of yearling Dall sheep was pregnant in Alaska.

Bighorn ewes are monestrous, and their estrous cycle lasts 2 days (Nichols 1978). Gestation for Rocky Mountain bighorns lasts approximately 175 days (Geist 1971), after which ewes typically give birth to a single lamb although twins do rarely occur (Welles and Welles 1961, Spaulding 1966, Geist 1971, Hoefs 1978, Nichols 1978, Eccles and Shackleton 1979). Fetal sex ratios do not differ from parity in wild, free-ranging sheep (Geist 1971). Captive adult ewes on a high nutritional diet have produced more female than male young (Hoefs and Nowlan 1994), indicating that the nutritional condition of ewes may influence their reproductive rate and the sex ratio of their offspring. However, Blanchard et al (2005), in a 29-year study of bighorn sheep in Alberta, found that maternal condition did not influence lamb sex ratios at birth. There is no evidence that social status of an adult ewe is correlated with her reproductive fitness or to any differential investment in her male or female offspring (Eccles and Shackleton 1986, Festa-Bianchet 1991a, Hass 1991, Blanchard et al. 2005).

The duration and degree of sexual segregation in wild sheep are functions of seasonality in the breeding cycle (Shackleton and Shank 1984). In some bighorn populations, male sheep gather on their fall or winter ranges 1 to 2 months prior to the breeding season, to establish and reinforce dominance relationships between individuals (Shackleton et al. 1999). It is during this pre-rut period that physical contact between males occurs. This competition for mating rights has led to the evolution of significant sexual dimorphism in horn and body size in wild sheep (Krausman and Shackleton 2000). Males with large horns typically dominate and do most of the breeding (Geist 1971, Hogg 1984, Hogg 1987, Shackleton 1991). However, near the end of the rutting period, or when male:female ratios are low, subadult males may have an opportunity to mate with estrous females (Shackleton 1973, 1976, 1991). Breeding by subadult males has resulted in more females serviced per male, fewer copulations per female, and more females successfully breeding during their second estrous in domestic sheep (Valdez and Krausman 1999). The probability of pregnancy, particularly of yearlings, is lowered as the number of rams declines. However, too many rams can cause mating interference and alter pregnancy rates (Smith 1954).

Mountain sheep are gregarious and polygamous (Geist 1971). Shackleton et al. (1999) suggested that, like domestic sheep, the presence of adult males in maternal groups acts to stimulate behavioral estrous and possibly the synchronization of estrous among females. The first sign of rut activity by males includes the males moving through maternal groups in "low-stretches," approaching the rear of females, and occasionally kicking the females with their foreleg (Geist 1971). Lip curling by males allows them to detect estrous with their vomeronasal organs (Estes 1972, Ladewig and Hart 1980), using a chemical pathway parallel to, but separate from the olfactory system. Before a female in estrous will accept copulation from any male, he must perform specific courtship behavior patterns (Geist 1971, Shackleton 1973, 1991): 1) nosing her flanks and rump, often while twisting his head and flicking his tongue in and out, 2) kicking the female with his foreleg, 3) standing with his chin on her rump, 4) pushing his chest against her rump, and 5) rising up to a pre-mount position (Shackleton et al. 1999). The adult ewe may reciprocate by actively courting a male, and she may even mount him in an effort to stimulate his interest (Geist 1971, Shackleton 1973).

Rocky Mountain bighorn males use four main mating tactics during the rut (Geist 1971, Shackleton 1973, Hogg 1987, Shackleton 1991). The most common method is "tending," in which a dominant male defends and copulates with a single, estrous female. The "coursing" method occurs most often in situation where the ratio of males to females is high, and it involves one or more males pursuing a female that is being defended by a tending male in an attempt to gain temporary access to a female (Geist 1971, Shackleton 1973). The "coursing" method rarely succeeds because the female runs away, followed by the subordinate males and the dominant male. In these situations, the dominant male will attack subordinate males in an attempt to chase them away. Occasionally, males will attempt to "block" a female's access to traditional tending areas where dominant males are located (Hogg 1984, 1987). The blocking action often occurs before the female is in estrous. Males that are able to keep the female away from the rutting area until she comes into estrous are more successful in copulating than males using the "coursing" strategy, but less so than males using the tending method. In areas with low male:female ratios, males will also "herd" one or more females (Shackleton 1973). When herding behavior occurs, there is always more than one male present, but the dominant male is not always the male herding the females. However, when the female does come into estrous herding behavior ends and the dominant male begins tending the female (Shackleton et al. 1999).

The observed variation in timing and duration of the birthing season for bighorn sheep is correlated with latitude. The season is later and of shorter duration with increasing latitude (Bunnell 1982, Thompson and Turner 1982), and it is related to thermal stress on newborn lambs and the need for sufficient high quality nutrition for lactating ewes (Sadlier 1969, Geist 1971, Festa-Bianchet 1988a, b). There is also a need for adequate time for growth by lambs before their first winter season. Lambs that are born late in the breeding season typically have higher mortality rates (Festa-Bianchet 1988c). Thus, the breeding season is a trade-off between giving birth early enough for adequate pre-winter growth and late enough to avoid thermal stress and poor forage conditions associated with late winter (Sadlier 1987). The birthing season for Rocky Mountain bighorn sheep begins in late April and early May, and it coincides with the timing of vegetation green-up and milder climatic conditions. Few lambs are born after June (Shackleton et al. 1999). The situation is somewhat different for desert bighorns, where plant production is related to temporal and spatial precipitation patterns, which vary considerably. The non-seasonal reproductive pattern of desert bighorns may be an adaptive strategy to ensure lamb survival during periods of unpredictable forage production (Leslie and Douglas 1979, Sandoval 1979a, Thompson and Turner 1982). Rachlow and Bowyer (1991) reported marked interannual differences in median birth dates for

Dall sheep in Alaska, and increasing evidence suggests that adjustments in gestation length may be under the proximal control of female Dall sheep (Berger 1992, Bowyer et al. 1998).

Lambing areas are usually on or very close to wintering areas and may be used year after year by the same maternal group (Geist 1971, Becker et al.1978). Adult ewes seek out steep, rugged topography for giving birth (Pitzman 1970, Rachlow and Bowyer 1991, 1994, 1998), which provides protection from predation, shelter from inclement weather, and isolation during the development of the mother-young bond (Shackleton et al. 1999). The shelter and isolation requirements for birthing ewes are generally short-term needs, suggesting that protection from predators may be a key factor resulting in relatively long isolation periods (Shackleton and Haywood 1985). Festa-Bianchet (1988a) reported that near-term ewes selected more secure habitat with poorer forage conditions over high-risk birthing areas with better forage, and suggested that predator constraints were an important consideration in selecting lambing sites. Cook (1990) observed a similar pattern with bighorn ewes in Wyoming.

The duration of labor in wild sheep is short, often lasting less than 20 minutes (Pitzman 1970). Lambs are precocial, typically standing within an hour, suckling in less than 3 hours, and walking within 2 hours of birth (Shackleton and Haywood 1985). Lambs are capable of traveling with their mothers within 24 hours of birth, feed on vegetation by 2 weeks of age, and are usually weaned between 3 and 5 months of age (Murie 1944, Pitzman 1970, Bunnell and Olsen 1976).

A variety of factors influence nursing behavior both among and within bighorn sheep populations. Festa-Bianchet (1988b) reported that maternal condition affected nursing during mid-lactation. He found young females, females with late born lambs, and females with heavy lungworm (*Protostrongylus* spp.) infestations allowed shorter suckling times and nuzzled their lambs less frequently than older, healthier females. Lambs born in an expanding bighorn population suckled less frequently but for longer periods, were refused by their mothers less often, and began grazing later than lambs from a stable population (Shackleton 1973).

Demography

Social behavior

Mountain sheep are very gregarious and spend much of their life in groups. Group integrity is not static and remains somewhat flexible throughout the year (Geist 1971, Leslie and Douglas 1979). Group composition consists of spatially and sexually segregated units of all male or female-juvenile groups made up of adult females, lambs, and 1 and 2-year-old offspring (Geist 1971). The size of these groups varies considerably depending on group type, season, and geographic location, and can consist of two to over 100 individuals (Geist 1971, Ashcroft 1986, Shackleton et al. 1999). There are two primary advantages to residing in groups: 1) improved foraging efficiency and 2) avoidance of predators (Pulliam and Caraco 1984). Predator avoidance appears to be the primary force in the formation and maintenance of groups in bighorn sheep (Jarman 1974, Jarman and Jarman 1979, Berger 1991). Rachlow and Bowyer (1998) found that individual animals in larger groups of thinhorn sheep spent more time feeding than those in smaller groups did and less time in vigilance or alarm behaviors. The distance sheep fed from secure cover also increased as group size increased (Hamilton 1971, Rachlow and Bowyer 1998).

Male and maternal groups of bighorns occupy separate seasonal ranges, but spatial and temporal overlap does occur during the breeding season (Geist and Petocz 1977, Morgantini and Hudson 1981, Krausman et al. 1989, Bleich et al. 1997). Differences in reproductive strategies between male and female bighorns are probably responsible for females selecting relatively secure areas for raising their offspring, while males generally choose areas with greater forage quality and quantity to maximize their body size (Main and Coblentz 1990, Main et al. 1996).

Fecundity and natality

Although Rocky Mountain bighorn females typically mate at 2.5 years of age, females in expanding populations and those under favorable environmental conditions can produce their first lamb at 2 years of age (Woodgerd 1964, Shackleton 1973, Jorgenson and Wishart 1984, Festa-Bianchet 1988b). For desert bighorns, mating at 1.5 years of age is not uncommon (McCutchen 1976, Sandoval 1981, Morgart and Krausman 1983).

Fecundity (i.e., mean number of live births in each age class) increases in bighorn sheep up to 5 years of age, after which there is a slight decline in productivity (Smith and Wishart 1978). Festa-Bianchet (1988b) observed a similar decline after 8 years of age, but it was not statistically significant. Despite limited evidence from Dall sheep (Singer and Nichols 1992), it does not appear likely that bighorn sheep pregnancy rates are influenced by the age structure of the male segment of the population. Shackleton (1973, 1991) showed that courtship behavior by males is a function of physical development and relative social status, not merely chronological age, and that most females were bred in a sheep population with no Class IV (FULL CURL) rams and a male:female ratio of 1:8. Pregnancy rates for bighorn sheep are over 90 percent in most Rocky Mountain bighorn populations (Sadlier 1987, Hass 1989, Jorgenson 1992). Although ewes have been observed suckling two lambs, and maternal groups have been observed with more lambs than adult ewes, bighorn sheep usually produce one lamb per year. Substantiated reports of twinning exist from observations of twin births (Gammill 1941, cited in Buechner 1960), of twin fetuses *in utero* (Spaulding 1966), and from cases where researchers were closely observing sheep populations (Van Dyke 1978, Eccles and Shackleton 1979). However, twinning is so infrequent in bighorn sheep that it has little effect on population growth rates (Krausman et al. 1999).

The genetic potential for growth in an ungulate population equates to the intrinsic rate of natural increase in a population where no resources are limiting (Caughley 1977). Bighorn sheep have the biotic potential, in the absence of disease, to double their population size every 4 to 5 years, and are relatively robust to significant variations in annual recruitment rates and mortality (McCarty and Miller 1998). Buechner (1960) calculated a conservative estimate for the intrinsic rate of increase for bighorns at 0.258, using the assumptions of one lamb per female per year, first birth at 3 years of age, an even sex ratio, stable age distribution, and no mortality. Empirical data show wild, free-ranging bighorn herds increasing at a rate of 0.288 on the National Bison Range, and at 0.265 over 11 years and 0.305 over 4 years in the Fort Peck sheep herd (Hass 1989). However, the high rates that Hass (1989) observed may have resulted from sex ratios that were skewed towards ewes.

Sex ratio

In unmanipulated bighorn sheep populations, adult sex ratios are usually near unity (Buechner 1960, Geist 1971). McQuivey (1978) reported similar sex ratios in hunted (60:100) and unhunted (57:100) desert bighorn populations. Woodgerd (1964) reported a sex ratio shift on Wild Horse Island, Montana in favor of males as population growth declined. Geist (1971) and Shackleton (1973) found more male than female yearlings in stable sheep population on low quality habitats and the opposite situation in expanding populations on high quality ranges, suggesting that environmental conditions may influence differences in juvenile survival. Blanchard et al. (2005) reported that maternal condition had no detectable influence on the sex ratio of lambs but did observe a non-significant trend towards fewer males being produced at high densities in a bighorn sheep population in Alberta. Festa-Bianchet (1989b) showed that male offspring were more energetically "costly" to rear than females because they grew faster and required greater investment in lactation. These data are contrary to an expectation that adult ewes would be more likely to raise the least "costly" sex successfully on low quality ranges (Krausman et al. 1999).

Mortality

Factors other than disease that influence mortality rates in bighorns may include inclement weather, inbreeding depression, poor maternal condition, poor mothering skills, human disturbance, and predators. At the root of these proximal mortality factors are those population and habitat conditions that lead to extreme birthing dates, poor range conditions, high population density, and the quality of escape cover (Hass 1989).

Bighorn lambs are particularly vulnerable to death in their first year of life (Blood 1961, Morgan 1970). In many ungulate species, maternal condition and birth weight are linked to mortality in the first year (Geist 1971, Clutton-Brock et al. 1987, 1992). Other factors influencing neonatal mortality in bighorn sheep are birth date, range condition, population density, the quality of security cover, and predation (Shackleton et al. 1999). Mortality in bighorn lambs is generally concentrated during two periods, post-natal and the lamb's first winter (Clutton-Brock et al. 1997). Mortality of lambs is often highest in the first few weeks after parturition (Blood 1961, Stewart 1980, Hoefs et al. 1986, Festa-Bianchet 1988c) and commonly results from predation, while winter mortality is often a result of poor nutritional condition (Festa-Bianchet 1988c). However, significant mortality can also occur in mid-summer due to disease epizootics (Woodard et al. 1972, Spraker 1974) or poor quality summer forage, which predisposes lambs to enzootic disease pathogens (Cook 1990).

Birth date can be a very important influence on survival in the first year (Bunnell 1982, Thompson and Turner 1982, Clutton-Brock 1987). Festa-Bianchet (1988c) found that 71 percent of bighorn sheep lambs were born during the first 15 days of the lambing season and their birth date affected subsequent survival. Lambs born early in the lambing season (May-June 10) were more likely to live to 5 months of age than those born later in the season, and only 5 percent of lambs born after June 10 survived to reproduce. Festa-Bianchet (1988c) speculated that lambs born late in the season missed the nutritional peak and were not able to put on the growth needed for long-term survival. Cook (1990) observed a similar pattern in a bighorn sheep population in south-central Wyoming. Hass (1989), on the other hand, found no relationship between birth date and survival in a less severe climate.

Woodgerd (1964) recorded no early mortality in a rapidly expanding population of bighorns. Festa-Bianchet (1988c) reported 96 to 97 percent survivorship of lambs in another population, and suggested that high early mortality often occurs when predation is a major factor. Predation rates upon lambs vary among bighorn populations, and can be as high as 80 percent in some populations (Hebert and Harrison 1988). Harper (1984) and Hass (1989) reported that high coyote (*Canis latrans*) predation levels on lambs tended to occur in areas with limited security cover or in areas that were not historical sheep ranges.

Based on data from skulls collected in the field, Murie (1944) and Geist (1971) estimated very low mortality rates for yearling and 2-year-old bighorns. However, estimates derived from declines in cohort numbers from several bighorn populations suggest that mortality rates for yearlings and 2-year-olds were considerably higher than those reported from studies using collected skulls (Festa-Bianchet 1989b). Stewart (1980) estimated yearling mortality at 33 and 41 percent for males and females, and 41 and 16 percent for male and female 2-year-olds, respectively. Festa-Bianchet (1989b) reported estimates of 33 percent for yearling males and 18 percent for 2-year-old males.

Comparisons of age-specific mortalities in adult male Rocky Mountain bighorn sheep showed that populations exhibited similar mortality patterns of 3 to 14 percent for 3 to 5-year-old rams, after which mortality rates dramatically diverged. Stable, unhunted bighorn populations that were nutritionally limited tended to exhibit slowly increasing mortality rates and long life expectancy. On the other hand, rapidly increasing and hunted populations on excellent ranges tended to show rapidly increasing male mortality rates with shorter life expectancies (Geist 1971, Jorgenson and Wishart 1984, Festa-Bianchet 1989b). Survivorship of older age classes of males can be also be expected to drop dramatically due to vigorous rutting activity (Geist 1971) or hunting strategies that target older rams.

Several authors have suggested that female mortality rates are higher than those of male bighorns (Sugden 1961, Woodgerd 1964, Bradley and Baker 1967, Hansen 1980b, Stewart 1980). Using radio-telemetry, Hengel et al. (1992) estimated annual female mortality rates at almost 11 percent in a Wyoming bighorn population. Shackleton et al. (1999) thought it was reasonable to expect that adult female bighorns would suffer higher mortality rates than males would because females are subjected to the stressors of reproduction some 5 to 6 years earlier than males, who typically do not begin breeding until they are 7 to 8 years of age.

Population limitation and regulation

Many bighorn sheep populations can be broadly described as numerically stable, but occasionally subjected to large-scale, catastrophic die-offs (Shackleton et al. 1999). A variety of factors potentially function to limit or reduce bighorn numbers, including food availability, interspecific competition, predation, and disease. Skogland (1991) documented six studies that found food resources limiting for ungulates; however, no data are available to demonstrate that food regulates or limits bighorn populations (Krausman and Bowyer 2003). Although abundant, good quality foods are generally available to sheep at other times of the year, winter forage availability, in most cases, has the capacity to be a primary limiting resource for bighorns (Shackleton et al. 1999). Cook (1990), however, suggested that the quality and quantity of summer and early fall forage could influence bighorn sheep lamb survival and was more critical to bighorns than winter forage quality in south-central Wyoming.

Localized interspecific competition for forage, space, and water between bighorn sheep and domestic livestock, elk, feral burros, and exotic wild sheep and goats is a potential limiting factor for many bighorn populations (Streeter 1969). Overgrazing by domestic livestock, particularly goats and sheep, has the potential to degrade bighorn habitat through significant changes in plant composition and density, leading to reduced carrying capacity for bighorn sheep. McQuivey (1978) and Steinkamp (1990) found that bighorn sheep avoided habitats occupied by cattle, and Bavin (1982) showed that cattle could be significant competitors with bighorns, especially in years with limited forage production due to drought. Cook (1990) suggested that heavy use of vegetation in riparian areas by cattle might preclude bighorn sheep access to critical vegetation resources during summer months. The conversion of grasslands to large shrub fields as a result of overgrazing by domestic livestock reduces the overall carrying capacity of bighorn sheep range and may lead to more predation by increasing hiding cover for stalking predators. The conversion of grasslands to shrub communities may also lead to higher numbers of deer and increased population densities of cougars (*Puma concolor*), which could compound the effects of competition and predation on bighorn herds.

Predation can also act as a limiting factor for bighorn sheep inhabiting ranges with inadequate escape cover (Harper 1984, Hass 1989). While predation on sheep occupying habitat with good escape cover is probably less important as a limiting factor, predation by cougars can be a significant factor limiting the growth of small, isolated sheep herds (Wehausen 1996, Hayes et al. 2000). Predation also has the potential to limit the recovery of bighorn populations that have declined precipitously because of a disease epizootic (Cassirer personal communication 2006). The major predators of bighorn lambs are probably coyotes and bobcats (*Lynx rufus*); golden eagles (*Aquila chrysaetos*) are known to kill lambs (Moser 1962, Wilson 1968, Watts 1979).

Disease is probably the most important limiting factor affecting bighorn sheep, often causing large (over 50 percent) and sudden (under 12 months) declines (Shackleton et al. 1999). Major bighorn sheep population declines have occurred in North America since the late 1800's, often resulting from contact with domestic sheep and environmental stress (DeForge et al. 1981, Goodson 1982, Onderka and Wishart 1984, Onderka et al. 1988, Brown 1989, de Vos 1989, Foreyt 1989, Ryder et al. 1994). Bighorns are susceptible to a variety of parasites and diseases, but Pasteurellosis appears to be responsible for many large-scale die-offs (Jaworski et al. 1993, Foreyt 1994). Lungworm infestations were originally thought to play a significant role in bighorn pneumonia episodes. However, Festa-Bianchet (1991b) argued that lungworm infestations are a "normal" condition in wild sheep and high levels of infestation do not predict pneumonia epidemics or indicate poor health in sheep. Dall sheep are also infected and infested with many disease organisms, including lungworms, but they have not suffered any major die-offs from lungworms and associated pneumonia (Gable and Murie 1942, Stelfox 1971, Shackleton 1985). In fact, there is no evidence that disease plays a major role in limiting or regulating Dall sheep populations (Krausman and Bowyer 2003). However, a major difference between Dall sheep and bighorn sheep populations has been the relative insulation of Dall sheep populations from exposure to domestic sheep and widespread contact of bighorn populations with domestic sheep.

Wehausen et al. (1987) described two principal ways that disease reduces the survival of bighorn sheep: 1) through pathogens introduced from external reservoirs and 2) from enzootic pathogens carried by bighorns. They suggested that disease pathogens affect mortality patterns in lambs differently based on the nutritional status of the lambs. However, lambs exposed to pathogens from domestic livestock experienced high mortality rates regardless of the nutritional status of the lambs. In contrast, mortality was low from enzootic pathogens unless predisposing conditions (e.g., poor quality summer forage) resulted in compromised immunological response in the lambs (Cook 1990). Other researchers have hypothesized that enzootic pneumonia pathogens may exist for many years in bighorn herds without causing major die-offs, and then become virulent throughout the herd when a member of the herd is weakened because of old age or environmental stress (Cassirer personal communication 2006).

Jorgenson et al. (1997) reported that juvenile females were the only class whose survival was affected when a bighorn population was allowed to increase to equilibrium numbers. No density-dependent effects on survival were detected in populations that were held below carrying capacity. Festa-Bianchet et al. (1995) showed that age-at-first-reproduction shifted from 2 to 3 years of age as the number of females dramatically increased. A similar shift was not observed in another population where female numbers did not vary as much.

These relationships suggest that density-dependent forces on fecundity and lamb survival regulated bighorn sheep populations, and that density-dependence may begin to manifest itself at "intermediate" population levels (Jorgenson et al. 1997). Population growth in bighorn sheep is a function of adult female survival and recruitment of young into the population. Population modeling demonstrates that growth is very sensitive to changes in adult female survival and less so to variability in annual recruitment. However, disease epizootics are known to cause chronically low lamb survival, resulting in significant reductions in recruitment in many bighorn herds. Therefore, large reductions in recruitment over several years can seriously affect population growth rates and may be as important as adult female survival in determining population status (Cassirer personal communication 2006).

A hypothetical flow chart depicting biotic and abiotic factors that potentially limit bighorn sheep populations in Region 2 is presented in **Figure 6**.

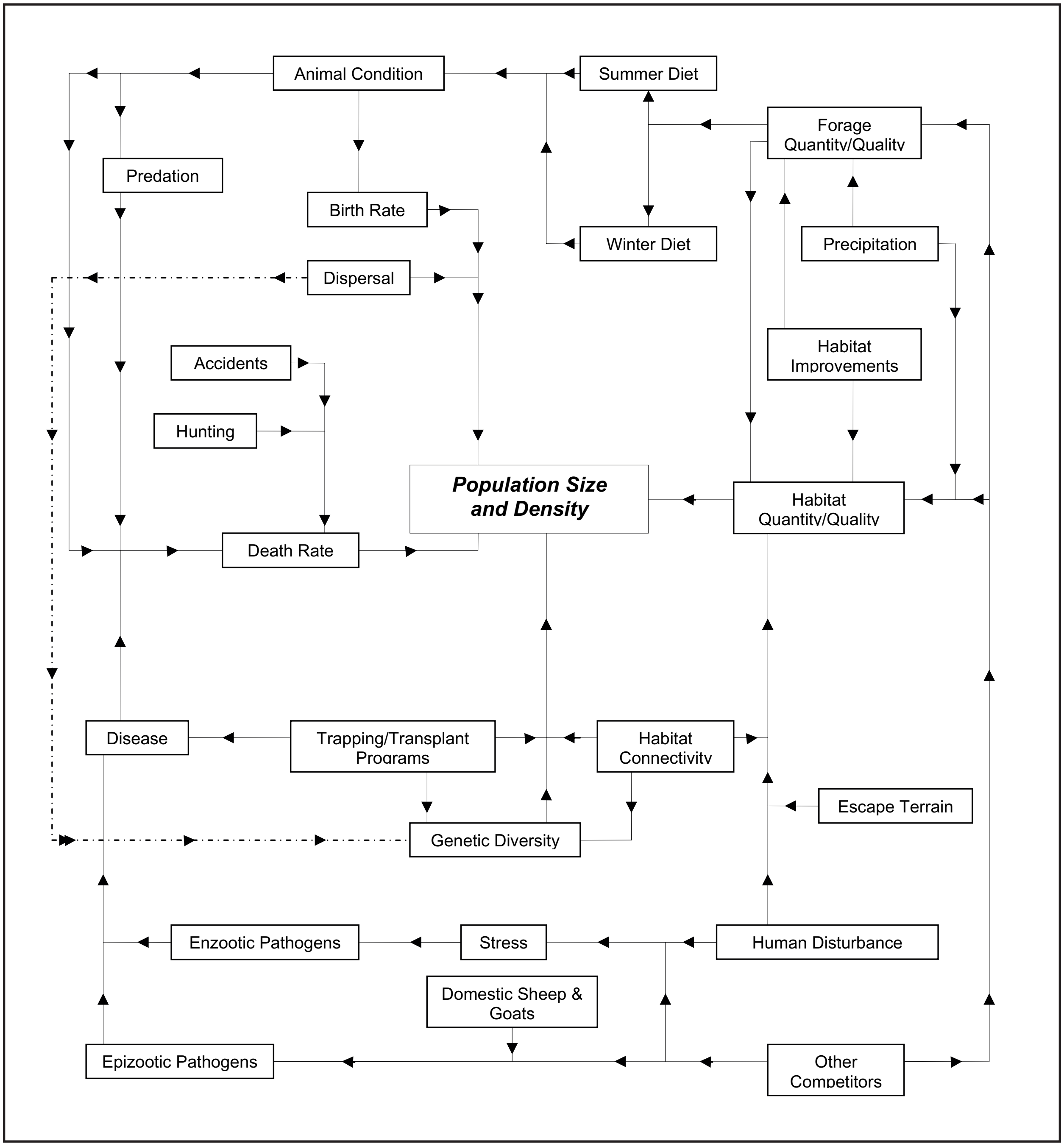

Figure 6. Hypothetical flow diagram of biotic and abiotic factors that influence bighorn sheep populations in USDA Forest Service Region 2.

Population persistence

Bighorn sheep occupy only a portion of their historical range in the western United States. In many cases, bighorns occur in isolated habitats and in small (less than 150) numbers (Toweill and Geist 1999). Although population size alone may not be an accurate predictor of bighorn sheep persistence in any given area (Krausman et al. 1993), small populations are generally at greater risk of extirpation than large populations occupying large contiguous habitats (Krausman and Leopold 1986, Berger 1990, Bleich et al. 1990b, Berger 1999, Wehausen 1999).

Berger (1990) suggested that bighorn herds consisting of less than 50 individuals were highly susceptible to rapid extirpation. He indicated that small population size was likely a driving force in rapid extinctions, and food shortages, changes in weather, predation, and interspecific competition were not major factors in the persistence of small populations. Jorgenson (*In litt*. July 2006) suggested that stochastic events, including predation and disease, could be important factors affecting the persistence of small herds. Berger (1990) stated that no empirical data existed to demonstrate effects of inbreeding in wild populations, as did Caro and Laurenson (1994). However, Berger (1990) implied that loss of genetic variability might play a role in the extinction of small (less than 50) bighorn populations. Krausman et al. (1993) and Wehausen (1999) took exception to Berger's (1990) conclusions when they identified several small bighorn sheep populations in Arizona and California that either continued to persist or increased significantly after populations declined below the 50 individuals cited by Berger (1990) as an extinction threshold. Krausman et al. (1993) and Wehausen (1999) suggested that environmental fluctuations and improved management practices (e.g., reduced grazing of domestic sheep in bighorn habitats, population augmentation efforts, lungworm treatment programs) likely contributed to the observed increases in numbers and persistence experienced by many small bighorn populations. Berger (1999) also concluded that changes in land management practices might be an important reason that small bighorn sheep populations persist longer today than they did prior to 1938. Hogg et al. (2006) examined the effects of experimentally restoring immigration to a wild bighorn sheep population (average size of 42 individuals over 10 to 12 generations) established in 1922 with 12 individual bighorns. They reported observing improvements in reproduction, survival, and five fitness-related traits among the descendants of the 15 recent migrant bighorns, suggesting that restoring gene flow by enhancing connectivity among sheep herds or by augmenting small, isolated herds had beneficial conservation implications.

Singer et al. (2001) used empirical models to predict the effects of disease epizootics and habitat patch size on the viability of bighorn sheep populations. They suggested that sheep herds with less than 250 individuals were more prone to extinction than large herds. Although large herds occupying large blocks of contiguous habitat were less prone to extinction, disease epizootics, nevertheless, had the potential to significantly impact the demographic structure of the herd and cause disease-induced extinctions (Gross et al. 1997, Gross et al. 2000). Hess (1996) explored the implications of disease in metapopulation models and concluded that increased contact among bighorn sheep populations could enhance the spread of disease and trigger epizootics. Mollison and Levins (1995) reached similar conclusions using epidemiological models that examined movement rates and the prevalence and spread of disease. However, Gross et al. (2000) reported that there was a tradeoff between high rates of colonization that resulted in faster and sustained population growth rates, and the risk of disease transmission that might result in the extinction of local bighorn herds. Their simulations of population persistence in South Dakota bighorn herds suggested that extinction rates declined when dispersal rates increased.

Bighorn sheep behavior patterns are extremely rigid and ritualized and play an important role in population persistence (Geist 1971). Studies suggest that bighorns do not adjust well to perturbations in these behavioral patterns (Geist 1971, Krausman 1993, Krausman et al. 1995). Consequently, human disturbance may be a factor disrupting bighorn behaviors and movements and may contribute to population declines. Extensive movement patterns by male bighorn sheep during the rutting season may increase their risk of coming into contact with domestic sheep and contribute to the perpetuation of disease in this species and significantly influence the probability of long-term persistence in isolated sheep populations (Gross et al. 2000).

Major epizootics appear to be a proximal cause of the extirpation of some bighorn populations and are a significant threat to populations that have been reduced in numbers due to habitat loss (Leslie and Douglas 1979, Krausman 1985, Gionfriddo and Krausman 1986, Krausman et al. 1989, Harris 1992). In particular, small (less than 150) populations may be vulnerable to extinction as a result of disease epizootics. While large (over 250) populations appear to be less prone to extinction from disease epizootics, modeling studies (Singer et al. 2001) suggest that disease can significantly alter population demographics, also leading to extinction. However, larger population size and habitat connectivity of herds can increase the likelihood of persistence when faced with a disease outbreak (Gross et al. 2000).

Community ecology

Predation

Wild sheep evolved with a variety of potential predators, and predation on wild sheep is well documented in the literature. However, the impacts of predation on wild sheep were not well studied until recently (Hoban 1990, Wehausen 1996, Ross et al.

1997, Hayes et al. 2000, Rominger and Weisenberger 2000, Logan and Sweanor 2001). These more recent studies indicate that under some circumstances, predation can be an important source of mortality in bighorn sheep herds.

Most reports of predation on bighorns involve coyotes and cougars, but golden eagles, lynx (*Lynx canadensis*), bobcat, and bears (*Ursus* spp.) are known to prey on bighorn sheep occasionally (Kelley 1980, Nichols and Bunnell 1999). Thorne et al. (1979) reported that coyote predation occurred primarily on lambs in areas of poor escape cover, and was not likely a limiting factor for bighorn sheep. Although numerous other studies document coyote-bighorn interactions, none suggests that coyotes are capable of regulating the growth of free-ranging bighorn sheep (McCann 1956, Buechner 1960, Moser 1962, Woolf and O'Shea 1968, Geist 1971, Shank 1977, Berger 1978, Creeden and Schmidt 1983, Festa-Bianchet 1988a, Berger 1991, Bleich 1996, Bleich 1999).

Cougars, however, prey on all age and sex classes of bighorns (Williams et al. 1995, Bleich et al. 1997, Ross et al. 1997, Hayes et al. 2000, Schaefer et al. 2000) and do appear capable of causing significant mortality in bighorn sheep populations, even where suitable escape habitat exists (Hoban 1990, Ross et al. 1997, Hayes et al. 2000, Logan and Sweanor 2001). The vulnerability of the various bighorn age and sex classes depends on the behavior of individual cougars rather than on the total number of cougars, as well as other factors (Hornocker 1970, Hoban 1990, Ross et al. 1997, Logan and Sweanor 2001). Predation on the non-reproductive segment of a bighorn population should have minimal impact on bighorn numbers because that mortality is likely to be compensatory in nature (Murphy 1998). However, predation on adult ewes may be additive to natural mortality, and can have an impact on bighorn sheep populations, especially small herds (Wehausen 1996, Hayes et al 2000). Ross et al. (1997) found no evidence that cougar predation levels could be explained by changes in bighorn numbers or the availability of alternate prey. Logan and Sweanor (2001) reported that a decline in the density of primary prey (i.e., mule deer) could exacerbate predation on bighorn sheep; they concluded the density of bighorn sheep was less important than the density of primary prey in determining the predation rates on bighorn sheep in the San Andres Mountains, New Mexico.

The indiscriminate removal or population-level reductions in cougar numbers does not appear successful in reducing the number of bighorns killed by cougars (Hoban 1990). However, identifying and removing individual cougars that prey on bighorn sheep was an effective method for minimizing bighorn losses to cougar predation (Linnell et al. 1999). Although predation is rarely significant in limiting bighorn sheep population growth, predation on small, remnant populations or recently transplanted bighorns can be limiting or cause local extirpations (Welsh 1971, McQuivey 1978, De Forge 1980). Predation by cougars was responsible for transplant failures for desert bighorn sheep in Texas, Nevada, and Utah, and it was a major mortality factor on a remnant bighorn herd in the San Andres Mountains, New Mexico (Broadbent 1969, Kilpatric 1982, Hoban 1990, Logan and Sweanor 2001). Significant predation losses to cougars (over 30 percent) occurred in recently transplanted bighorn sheep herds in Colorado, New Mexico, and Arizona (Creeden and Schmidt 1983, Elenowitz 1983, Remington 1983).

Competition

Interspecific competition for space and forage is a serious threat to many bighorn sheep populations. Competition arises when two species use resources that are in short supply and one species is harmed in the process (Pianka 1978). In particular, competition with domestic livestock has proved to be a significant factor in maintaining the distribution, health, and viability of bighorn sheep herds across the West. A variety of domestic and exotic ungulates can compete with bighorn sheep for forage, water, and space. Domestic livestock grazing can affect bighorn sheep habitat by reducing carrying capacity through large-scale changes in plant composition and density, including changes from grassland to shrub-dominated landscapes that other ungulate species, like mule deer, favor (Krausman and Bowyer 2003). Overgrazing by livestock in the late 1800's and early 1900's resulted in large-scale changes in the composition of native plant communities, including the reduction of plant species important to bighorns, ultimately leading to long-term reductions in the carrying capacity of habitats for bighorn sheep. Competition for space and food, and changes produced in vegetation communities, are thought to have reduced population vigor in many bighorn sheep herds, leading to increased mortality, decreased productivity, or increased dispersal rates (Gallizioli 1977, Krausman et al. 1999). Densities of adult sheep on summer ranges were shown to be inversely correlated with lamb production and survival, suggesting that intraspecific competition is also a factor limiting bighorn sheep populations (Woodgerd 1964, Geist 1971, Douglas and Leslie 1986). The presence of cattle on bighorn sheep ranges may artificially reduce the amount of habitat available to bighorn sheep, resulting in increased densities (Wilson 1968, Jones 1980, Dodd and Brady 1986, Steinkamp 1990).

Although cattle prefer gentler slopes than wild sheep, bighorn sheep have abandoned traditional ranges when cattle were introduced (Wilson 1968, Jones 1980, Dodd and Brady 1986, Steinkamp 1990). Bavin (1975) concluded that cattle were a serious competitor with bighorn sheep in New Mexico, where he documented 12 of 18 major forage species were common to the diets of both. Cook (1990) suggested that heavy cattle use of riparian zones in xeric environments might preclude bighorn sheep from accessing high quality vegetation during critical summer months. Competition between bighorn sheep and cattle was considered a serious problem in British Columbia (Demarchi 1965) and Idaho (Morgan 1973), and Halloran and Kennedy (1949) reported that cattle often kept desert bighorns from habitat adjacent to critical water sources in narrow canyons in Arizona. Areas grazed by cattle supported significantly lower densities of desert sheep (2.3 sheep per km^2) than ungrazed ranges (6.6 sheep per km^2) in Nevada (McQuivey 1978). Spatial and forage competition, especially with cattle, continues to limit bighorn sheep populations where they overlap, and may be an important obstacle to the reintroduction of bighorn sheep into historical habitats (Gallizioli 1977, Sandoval 1979b).

Competition with domestic sheep and goats is considered even more serious than with cattle because of their similar preferences in forage and topography. Furthermore, domestic sheep and goats harbor parasites and diseases that are lethal to bighorn sheep (Krausman and Bowyer 2003). Desert bighorns were extirpated from historic habitats in California (Weaver 1972), Arizona (Russo 1956, Gallizioli 1977), Nevada (McQuivey 1978, Kelley 1979), New Mexico (Gross 1960, Mendoza 1976, Sandoval 1979b), Utah (Wilson 1968, Dean and Spillet 1976), and Texas (Davis and Taylor 1939, Kilpatric 1982) due to competition for forage and space, and from disease transmitted from domestic sheep (Bunch et al. 1999). Feral burros (*Equus asinus*), aoudad (*Ammotragus lervia*), and Persian goats (*Capra aegagrus*) also pose a significant threat to bighorn sheep where their ranges overlap (Sandoval 1979b). The habitat requirements of aoudad and Persian wild goats are very similar to those of desert bighorns, resulting in direct competition for resources (Bavin 1975, Simpson and Krysl 1981). These species are capable of excluding bighorn sheep from critical resources or out-competing them (Bailey 1980).

There is considerable overlap in the diets of bighorn sheep and elk, and to a lesser extent, mule deer and mountain goats (*Oreamnos americanus*) (Streeter 1969). Elk are potentially serious competitors with bighorns in areas where their winter ranges overlap (Lawson and Johnson 1982). Picton (1984) reported that lamb:ewe ratios declined in the spring after heavy grazing by elk on bighorn sheep winter ranges. In some areas, wintering elk can become so numerous that potential forage for bighorn sheep becomes unavailable because trampled snow forms an icy crust over the vegetation and prevents access by sheep (Cowan 1947). However, no deleterious effects were observed from interspecific competition with deer on desert bighorn sheep (Halloran and Kennedy 1949, Smith 1954, Jones et al. 1957).

Parasites and diseases

Coincident with the introduction of domestic sheep to western ranges in the latter 1800's and early 1900's, bighorn sheep declined dramatically, both geographically and in total numbers throughout western United States. This decline appears to have resulted largely from the transmission of diseases common to domestic sheep to naïve bighorn populations (DeForge et al. 1981, Brown 1989, de Vos 1989). Between 1900 and 1960, the effects of competition with and overgrazing by domestic livestock, habitat fragmentation, and unregulated harvest for subsistence, further contributed to declines in bighorn sheep populations.

Significant bighorn sheep die-offs have occurred in every western state from the late 1800's to the present (Martin et al.1996, Toweill and Geist 1999). These large-scale epizootics were thought to be caused by macroparasites, bacteria, and viruses (Spraker 1977, de Vos et al. 1980, King and Workman 1983, Onderka and Wishart 1988, Onderka et al. 1988). Transmission of pneumonia and scabies infections from domestic sheep to bighorns was implicated in epizootics in Colorado, Wyoming, Idaho, Arizona, and New Mexico (Lange et al. 1980, Jessup 1985, Ward et al. 1997). Chlamydia, possibly in combination with *Pasteurella* pneumonia, was a proximate factor in the decline of several bighorn sheep herds in south-central Wyoming (Cook 1990). For the past 20 years, scabies has been a significant mortality factor among bighorn sheep in the San Andres Mountains in New Mexico (Lange et al. 1980, Hoban 1990, Rominger and Weisenberger 2000). Clark et al. (1985) found evidence of parainfluenza-3 (PI-3), lungworm, bluetongue (BTV) and epizootic hemorrhagic disease (EHD), respiratory syncytial virus, bovine viral diarrhea, and contagious ecthyma virus in 18 herds of desert bighorn sheep in California.

Although bighorn sheep have been exposed to many disease pathogens, very few are considered a major threat to population viability. Diseases that are widespread in the United States and known to occur in bighorns, apparently with little population level risk, include respiratory syncytial virus, leptospirosis, parainfluenza-3 (PI-3), infectious bovine rhinotracheitis, anaplasmosis, infectious keratoconjunctivitis, and contagious ecthyma (Dubay et al. 2003, Jansen et al. 2006). Bovine viral diarrhea and brucellosis are also widespread, but little is known about their potential for causing significant disease outbreaks in bighorn sheep populations. Contagious ecthyma can be very debilitating and result in stunted growth in bighorn sheep, especially where artificial salting is common (Blood 1971, Samuel et al. 1975, L'Heureux et al. 1996). Respiratory syncytial virus and PI-3 have been implicated in predisposing bighorn sheep to *Pasteurella* spp. (*Mannheimia* spp.) outbreaks (Miller 2001). Infectious keratoconjunctivitis (IKC) is a disease that causes temporary blindness and affects domestic livestock throughout the world (Jones 1991). IKC has been documented in bighorn sheep in Arizona as a result of contact with domestic goats (Jansen et al. 2006). Paratuberculosis (Johne's Disease) is a bacterial infection that causes chronic enteritis in some free-ranging ungulates. It has been documented in bighorn sheep and has the potential to cause isolated problems throughout bighorn range (Williams 2001). Bighorn herds documented with positive titers to paratuberculosis may not be suitable candidates as source stock for transplant programs (Timoney et al. 1988). Despite the fact that these disease pathogens appear to pose minor risks to bighorns, it is not clear how interactions among these disease organisms may predispose bighorns to more significant disease epizootics.

Diseases that do pose a significant health risk include BTV, EHD, scabies, and pasteurellosis. BTV and EHD are two closely related viruses that occur in many ungulates, including bighorn sheep (Robinson et al. 1967, Thorne et al. 1982, Noon et al. 2002). A Culiocoides gnat transmits BTV and EHD to bighorns, and epizootics are most prevalent during the wet season or around water holes in the dry season. Bighorn deaths resulting from exposure to BTV and EHD have been documented in California, Wyoming, Arizona, Texas, and Idaho (Robinson et al. 1967, Jessup 1985, Heffelfinger et al. 1995, Noon et al. 2002). Positive titers to BTV and EHD indicate past exposure to the viruses, but they do not necessarily indicate current disease status in the animal (Thorne et al. 1982). Bighorn sheep and other free-ranging ungulates have been documented with positive titers to BTV and EHD, with no evidence of clinical disease, suggesting that the viruses are enzootic in the western United States (Thorne et al. 1982).

Pasteurellosis is a bacterial disease that ranks as one of the most important respiratory diseases found in bighorn sheep, leading to pneumonia and death (Foreyt 1993). *Pasteurella* spp. (and *Mannheimia* spp.) is part of the normal bacterial flora of both domestic and wild sheep (Ward et al. 1990). However, very large, all-age die-offs of bighorn sheep are associated with exposure to some species and biotypes of *Pasteurella* and *Mannheimia*. Over 70 varieties of *M. haemolytica* and *P. trehalosi* (formerly known as *P. haemolytica* biotypes A or T) are known to occur in domestic and wild sheep. *Mannheimia haemolytica* is more common in domestic sheep while *P. trehalosi* is the most common species in many wild ungulates, including bighorn sheep (Foreyt 1993, Jaworski et al. 1993). *Mannheimia haemolytica* serotype A2 has been proven to kill bighorn sheep and may be the most important pathogen responsible for bighorn sheep die-offs after contact with domestic sheep (Jaworski et al. 1993, Foreyt 1994).

Martin et al. (1996) documented over 30 cases where bighorn die-offs were associated with contact with domestic sheep. Experimental exposure of captive bighorn sheep to elk, deer, mountain goats, cattle, and llamas has not resulted in pneumonia outbreaks in bighorns (Foreyt 1992, 1993, 1994). *Pastuerella multocida* and *P. trehalosi* may also be important in the pneumonia complex, and they, as well as *Mannheimia haemolytica*, can be directly transmitted to bighorns from domestic sheep (Onderka and Wishart 1988, Foreyt 1989, 1990, 1992). Virulence may also be acquired by normally avirulent types of *Mannheimia* or *Pasteurella* through the horizontal transfer of the leukotoxin A (lktA) gene between strains. Although this is not always associated with the occurrence of disease in bighorn sheep, the detection of horizontal gene transfer suggests that recombination may be involved in the development of virulent strains of *Pasteurella* and *Mannheimia* (Hells Canyon Bighorn Sheep Restoration Committee 2004). Domestic goats can also carry *Pasteurella* spp. that may be lethal to bighorn sheep (Ward et al. 2002). Rudolph et al. (2003) reported that some *Pasteurella* isolates collected from bighorn sheep and domestic goats sampled during the Hell's Canyon epizootic were genetically identical, suggesting that goats may have played a role in the 1995-1996 die-off in Hells Canyon, Idaho.

All-age mortality occurs during a bighorn sheep pneumonia die-off, often resulting in the loss of 75 to 100 percent of the herd. Where a pneumonia die-off has occurred, lamb survival may be depressed for three or more years after the initial episode, and herd recovery is slow (Foreyt 1990, Coggins and Mathews 1992, Ward et al. 1992). Apparently, lambs born to surviving ewes are initially protected from the *Pasteurella* spp. or *Mannheimia* spp. pathogen for six to eight weeks by passive colostrums in their mother's milk, but they usually die within three months as that protective immunity is lost (Foreyt 1990). Although chronically low lamb survival is not as dramatic as an all-age die-off in terms of reducing bighorn sheep population size, over the long term, it may be just as important (Cassirer personal communication 2006).

The science has so overwhelmingly demonstrated the threat posed by domestic sheep to persistence of native wild sheep, that in 1995 the U.S. District Court in Oregon ruled that domestic sheep and bighorns were incompatible and should be kept separated from one another on Hells Canyon National Recreation lands. That ruling led the USFS to develop a process for finding management solutions on National Forest System lands to address the issue of incompatibility between domestic sheep and free-ranging bighorns (Schommer and Woolever 2001). Although horses, mules, burros, and llamas are not considered disease threats to bighorn sheep (Miller et al. 1995, Foreyt and Lagerquist 1996), desert bighorn sheep biologists (in Trefethen 1975) recommended that wild, free-ranging burros, horses and livestock should be removed from desert bighorn sheep habitats as a result of serious competitive (forage and space) problems.

Pneumonia die-offs have also occurred in bighorn herds with no known exposure to domestic sheep or goats (Goodson 1982, Onderka and Wishart 1984, Foreyt 1989, Ryder et al. 1994, Miller et al. 1995). These die-offs were thought to be caused by *Pasteurella trehalosi*, serotypes 3, 4, and 10, and they may have been triggered by environmental factors (severe winter or drought), by association with other bacteria or viruses, or by the sheep population exceeding the carrying capacity of its habitat. Cook (1990) suggested that protein malnutrition was a significant factor predisposing bighorn lambs to disease by retarding the development of organs that regulate their immune system. Although it is clear that many strains of *Pasteurella* and *Mannheimia* are pathogenic to bighorn sheep and considerable research data are available on the effects of Pasteurellosis (Miller 2001), there is much that is not known.

Some promising research is underway at Washington State University in which the neutrophil cell-surface protein regions serving as receptor sites for pneumonia leukotoxins attachment have been identified. Homologous peptides have been synthesized, which, in vitro, conspicuously reduce the virulence of pneumonia leukotoxins. The objective of this research is to use these peptides to protect the bighorn sheep in a pneumonia die-off situation. The long term goal of this research is to develop a vaccine for wild, free-ranging, bighorn sheep (Srikumaran personal communication 2007).

Several intestinal parasites infect bighorn sheep, including thin-necked bladderworms (*Taenia hydatigena*), three species of tapeworms (*Moniezia* spp., *Thysanosoma actinoides*, and *Wyominia tetoni*), and several abdominal and gastrointestinal nematodes (Becklund and Singer 1967, Becklund and Walker 1967, Becklund 1969). Eleven species of *Eimeria* are found in bighorns and are responsible for coccidiosis, which causes diarrhea or "scours" (Lotze 1956). External parasites that infest wild sheep include winter and wood ticks (*Dermacentor* spp.); the spinose ear tick (*Otobius megnini*); two lice species (*Bovicola* spp.); and two species of dipterids, the botfly (*Oestrous ovis*) and sheep tick (*Melophagus ovinus*) (Imes and Babcock 1942, Gobbett 1956, Becklund and Senger 1967, KeChung 1977). In addition to direct effects on bighorn sheep health, several of these species have been implicated as potential intermediate hosts for disease agents.

Scabies is a highly contagious parasitic skin infection caused by *Psoroptes* mites (Becklund and Senger 1967). Scabies infection has resulted in clinical disease in free-ranging wildlife, and is commonly found in desert and Rocky Mountain bighorn sheep, elk, and white-tailed deer (Thorne et al. 1982). The highest densities of these mites can be found on domestic sheep bedding grounds (Kemper and Peterson 1956) and they have been implicated in the historical decline of bighorn sheep throughout the West, and more recently in Arizona, Nevada, and New Mexico (Carter 1968, Decker 1970, de Vos et al. 1980, Sandoval 1980). Mortalities caused by scabies reduced populations of bighorns at Greybull River, Wyoming (Honess and Frost 1942, Honess and Winter 1956), in Rocky Mountain National Park, Colorado (Wright et al. 1933, Packard 1946), in the Sierra Nevada mountain range in California (Jones 1959), and along the Owyhee River in Oregon (Bailey 1936). In general, scabies infection has the potential to cause substantial localized morbidity and mortality, especially in naïve animals (Dubay et al. 2003).

Conservation

Threats

A variety of factors threaten the long-term viability of bighorn sheep in Region 2. Developing an understanding of how these factors act to limit or threaten bighorn sheep is especially important because many sheep herds in the Region are small and susceptible to extirpation (Berger 1990, Fitzsimmons and Buskirk 1992, Krausman et al. 1993). Immediate threats to bighorn sheep herds in the Region include:

- the risk of deadly epizootics as a result of disease transmission from domestic sheep and goats to bighorns and between bighorn herds during translocation projects
- the loss of genetic variability in small herds
- habitat deterioration, loss, and fragmentation
- human disturbance on critical winter and lambing ranges
- competition for forage and space with livestock and other ungulate species
- cougar predation on adult female sheep in remnant or recently reintroduced herds.

Disease

The importance of disease to the conservation of bighorn sheep is likely to increase as habitat loss and fragmentation restrict their movements and concentrate them in smaller areas, increasing contact rates and the spread of disease pathogens (Scott 1988, Levins et al. 1994, Schrag and Wiener 1995). The effect of domestic livestock diseases on bighorn sheep is well documented (DeForge et al. 1981, Brown 1989, de Vos 1989, Foreyt 1993, Jaworski et al. 1993, Martin et al.1996), and disease continues to represent a significant threat to bighorn herds in areas where bighorns and livestock, primarily domestic sheep and goats, have an opportunity to interact. Although habitat fragmentation and loss are frequently cited as important factors influencing the persistence of bighorn sheep populations, disease is likely the factor that eventually results in the extirpation or extinction of many bighorn herds (Flather et al. 1994). Berger (1990) reported that bighorn sheep herds of less than 50 individuals had a much lower probability of long-term persistence than larger populations. A number of national forests in Region 2 still have active domestic sheep allotments in areas of bighorn sheep occupancy, suggesting that disease epizootics may play a significant role in the long-term persistence of many herds in the Region.

Most bighorn sheep herds occupy public lands in the western United States, and federal land management agencies have taken action to develop policies intended to minimize contact between domestic livestock (primarily sheep) and bighorns. In 1971, the Inyo National Forest in California established sanctuaries on the forest to regulate human use and to reduce the potential for contact between domestic and bighorn sheep, and these are still in place today (Wehausen 1979, Inyo National Forest Land Management Plan 1988). The BLM established guidelines in 1992 for managing domestic sheep in bighorn habitat; these guidelines were revised in 1998 to better reflect current knowledge regarding the interaction of bighorns and domestic sheep (BLM Memorandum 92-264). The USFS and USFWS published similar guidelines for national forests that issue domestic livestock grazing permits in bighorn sheep habitat (Schommer and Woolever 2001, U.S. Fish and Wildlife Service 2001). Concern about the long-term stabilization of wild sheep herds and the domestic livestock industry in Wyoming led to the formation of the Wyoming Bighorn/Domestic Sheep Interaction Working Group in 2000. This group of stakeholders, including representatives from USFS Region 2, identified issues of concern regarding interactions between bighorn and domestic sheep and produced a final report, including recommendations for actions, to the state in 2004 (Wyoming Statewide Bighorn/Domestic Sheep Interaction Working Group 2004). These documents summarized current information regarding the detrimental effects of interactions between domestic livestock and wild sheep, and described risk assessment probabilities, strategies for preventing contact, and management actions needed when contact between the two species has occurred.

Risk assessment involves considering the probabilities that (1) stray domestic sheep will occur near established bighorn populations, (2) strays will enter bighorn habitat, and (3) the two species will come into contact as a result of bighorn rams coming in contact with domestic sheep during exploratory movements. Decisions by management authorities can significantly influence the potential for stray domestic sheep to occur near and gain access to bighorn habitat. The potential for domestic sheep to access wild sheep habitat is a function of the distance separating the two species, the presence of potential barriers between them, and allotment grazing procedures. The propensity of male bighorns to travel over large areas further complicates managing domestic-bighorn interactions. Although these documents provide important information and guidance for federal land management agencies in their efforts to prevent contact between domestic and bighorn sheep, private land in-holdings on many forests still represent a serious threat to bighorn populations on public lands and should be considered in developing management plans for bighorn sheep in Region 2. The use of domestic goats as recreational pack animals and for weed control on national forests may also represent a disease transmission threat (Cassirer et al. 1998).

Genetic diversity

The potential loss of genetic variability is a serious threat to small, isolated bighorn herds throughout Region 2. Small populations of bighorns depend on interactions with other sheep to maintain population viability (Berger 1990, Bleich et al. 1990a). Increasing coefficients of inbreeding and genetic drift are products of decreasing population size and can lead to reduced levels of heterozygosity and inbreeding depression (Soulé 1980). A growing body of literature suggests that inbreeding and decreased levels of heterozygosity influence disease resistance, lamb survival rates, and horn growth in bighorn sheep (Sausman 1982, Stewart and Butts 1982, Fitzsimmons et al. 1995, Carrington et al. 1999, Coltman et al. 1999). The majority of bighorn herds in Region 2 have an effective population size of less than the 200 to 500 individuals that may be necessary for long-term survival (Franklin 1980, Lande and Barrowclough 1987, Brussard and Gilpin 1989, Berger 1990, Franklin and Frankham 1998). An examination of the distribution of herds in Region 2 reveals that many of the herds are isolated due to habitat loss, road construction, and human development. Intrusive management efforts will be necessary under current conditions to maintain genetic diversity or to improve reproductive performance and survival (Hogg et al. 2006). However, most bighorn herds in Region 2 have experienced at least one disease epizootic, and the threat of disease transmission during augmentation efforts is a more significant risk to the recipient herd than loss of genetic variability unless steps are taken to evaluate the disease status of both the donor and recipient bighorn herds prior to undertaking an augmentation program.

Habitat loss and degradation

The preservation and enhancement of critical, native bighorn sheep habitat are crucial to ensuring viable populations in the future (Stelfox 1976). Threats to bighorn habitat range from conversion of grasslands to forest types because of fire suppression, to fragmentation and loss due to competition with domestic livestock and human disturbance. Bighorn sheep are well adapted to open and fragmented habitats that provide high quality nutrition and allow sheep to detect predators at relatively long distances. As a result, they prefer areas characterized by openness and steep, rocky terrain. Historically, wildfires prevented the encroachment of forests onto open grassland habitats that sheep prefer (Elliott 1978), and they were instrumental in maintaining adequate foraging areas adjacent to escape terrain, as well as in preventing the encroachment of forests in migration corridors. However, fire suppression efforts in the latter half of the 20th century have resulted in the encroachment of forest and shrub communities into bighorn foraging habitat. Encroaching forests are also responsible for effectively blocking migration corridors between seasonal habitats and dispersal routes that lead to isolation of populations. Prescribed burns, designed to maintain the open character of migration corridors and to enhance the nutritive content of vegetation on winter ranges, are an important tool in range regeneration efforts by land management agencies. Prescribed burns and managed wildfire policies (especially in wilderness areas that are also experiencing vegetation succession that is detrimental to bighorn sheep) can be used to create or regain additional habitat or to reclaim functional movement corridors, and they may temporarily increase herd reproductive success by maximizing nutrient intake (Hebert 1973, Wehausen and Hansen 1988, Wehausen 1996).

Human disturbance

Wild sheep have habituated to human activity in many areas where the activity is somewhat predictable temporally and spatially. However, human disturbance (e.g., snowmobiling and heli-skiing on and near winter ranges) and human presence near lambing sites may be detrimental to bighorns in some locales (Graham 1980, MacArthur et al. 1982, Etchberger et al. 1989). Mineral exploration and extraction, road construction, harassment by low flying aircraft, and other human disturbances near lambing grounds had potential detrimental effects on Dall sheep populations (Nichols 1975, Hoefs and Barichello 1985, Poole and Graf 1985). Human development, especially in valley areas, may function to limit bighorn movements between mountain ranges occupied by bighorn sheep and become a critical factor in determining their long-term conservation prospects. In Region 2, human disturbance to bighorns occurs primarily on their winter ranges as a result of winter recreational activities, development projects at lower elevations (Linstrom 2005b; see also discussion on Waterton Canyon herd), and the presence of high traffic roads through areas used by sheep. At this point, the effects of human disturbance on bighorn sheep appear to vary considerably among areas, and managers should consider this treat on a case-by-case basis.

Competition

Competition between bighorn sheep and domestic livestock for forage, water, and space is another potential threat to bighorns in Region 2. Historically, competition with domestic livestock played a significant role in the decline of mountain sheep in western North America. Overgrazing by domestic livestock in the late 19th and early 20th century resulted in dramatic changes in the composition and density of plant communities. In many cases, preferred forage species for bighorn sheep either were reduced significantly or disappeared from native bighorn ranges, resulting in a decrease in carrying capacity of the habitat (McQuivey 1978). In those cases where severe overgrazing was responsible for conversion of grasslands to shrub-dominated communities, the habitat became more suitable to mule deer. Although there may be very little dietary overlap between bighorns and mule deer, high densities of mule deer likely support higher densities of predators, including both coyotes and cougars. This situation presents a difficult environment for bighorns because coyotes are capable of preying heavily on lambs and some cougars are successful predators on adult female bighorns. Competition between bighorns and livestock for forage is especially critical during periods of the year when forage is limited or of low quality (Bavin 1975). Although total forage production may exceed the needs of bighorn sheep during stress periods, the presence of cattle in riparian or alpine areas may reduce the availability of high quality forage to sheep (Cook 1990). In situations where cattle were experimentally introduced into occupied bighorn habitat, bighorns have been displaced from traditional ranges, suggesting that wild sheep were socially intolerant of cattle (Steinkamp 1990). Other researchers have reported that cattle were serious dietary and spatial competitors of bighorn sheep (Wilson 1968, Morgan 1973, Jones 1980). While the conversion of domestic sheep allotments to cattle allotments on many national forests in Region 2 has been a positive step in significantly reducing the threat of *Pasteurella* epidemics, it has not eliminated the potential for disease transmission, and competition for forage and space with domestic livestock remains a concern.

Predation

Bighorn sheep have co-existed with predators for thousands of years, and to minimize predation risks, they have evolved adaptive behaviors and physical capabilities, such as group living, diurnal activity patterns, and the ability to move efficiently in rough, precipitous terrain (Hamilton 1971, Alexander 1974). However, under some conditions, herds can become vulnerable to population level effects of predation. The impact of predation on bighorn sheep varies considerably as a result of differences in habitat characteristics, prey preferences of individual predators (primarily cougars), and primary prey densities (Ross et al. 1997, Schaefer et al. 2000, Logan and Sweanor 2001, Kamler et al. 2002, Sawyer and Lindzey 2002). Small remnant populations are particularly vulnerable to predation by cougars. Predation has been an important mortality factor leading to decreases in bighorn sheep numbers in California (Wehausen 1996, Hayes et al. 2000, Schaefer et al. 2000) and in Arizona (Kamler et al. 2002). Much of the variation in predation impacts can probably be attributed to disease-related reductions in bighorns across much of their historical range, the fragmented nature of bighorn distribution, the availability of alternative prey, and fire suppression that has altered bighorn habitat by decreasing forage quality, increasing ambush cover, and increasing the densities of deer. The vulnerability of newly transplanted bighorns to predation may be influenced by their prior experience with predators, suggesting that bighorns transplanted from sites where predators were absent may be more vulnerable to predation at new transplant sites that have resident predators (McCutchen 1982). Although it is difficult to come to any consensus regarding the effects of predation on bighorns, it appears clear that the reduction in bighorn numbers and distribution in the last 150 years has altered the dynamics between predators and bighorns across their range.

Conservation Status of Bighorn Sheep in Region 2

State heritage programs in Colorado and South Dakota classify bighorn sheep as secure, and in Wyoming as either vulnerable or secure, depending on the size and connectedness of individual herds (NatureServe 2003). However, these classifications appear not to have fully considered the potential for disease epizootics, population viability issues, and security of individual bighorn herds in the states. Therefore, these ranks may be overly optimistic for many herds. The relatively large numbers and widely-distributed bighorn herds in

Colorado and Wyoming might suggest that populations in these states are reasonably secure. However, this superficial picture of bighorn status in Region 2 fails to recognize the critical issues of small herd size in many populations, the long history and continued substantial risk of disease epizootics, increasing levels of habitat fragmentation, or the degree to which many herds have become isolated from other herds.

Diseases contracted from domestic livestock have reduced wild sheep populations significantly in the last century and a half, and they are currently one of the most important threats to herds in Region 2. Increasing habitat fragmentation in many areas of Region 2 has reduced or severely limited connectivity among many bighorn populations and reduced population sizes, exacerbating the potential for disease to eliminate herds. As habitat is fragmented, the vulnerability of bighorn herds to extirpation increases as the herds become smaller and are confined to smaller and smaller patches of habitat that may deny them access to important resources. The size, distribution, and quality of these habitat patches ultimately dictate the number of sheep that they can support. A number of herds in Region 2 (discussed below) are affected by habitat loss or fragmentation due to forest succession and human development on bighorn ranges. In some cases, fire suppression policies have allowed forest succession to interrupt bighorn migration corridors and to encroach on their habitat to the extent that the carrying capacity in herd units is declining. Because bighorns are slow to colonize new areas and frequently occupy fragmented habitats (Geist 1967, 1971, Bleich et al. 1990b, 1996), any changes to the character of their habitat or that further fragment existing herds may be a significant threat to the long-term persistence of regional populations (Schwartz et al. 1986, Bleich et al. 1996).

While bighorn sheep often exist in a naturally fragmented environment, corridors of suitable habitat connecting habitat patches increase the effective size of bighorn populations through metapopulation structuring (Noss 1987, Quinn and Hastings 1987, Simberloff and Cox 1987, Hudson 1991). The modest size of most bighorn herds suggests that a metapopulation structure is, or once was, operative in maintaining genetic variability in bighorn sheep (Gilpin and Hanski 1989, Bleich et al. 1990a). Bighorn sheep evolved with relatively conservative philopatric behaviors, and their reluctance to disperse from their natal ranges results in low colonization rates and low gene flow among populations (Geist 1967, 1971). Maintaining gene flow is important to the conservation of bighorn sheep because the loss of genetic variability can result in inbreeding depression, the inability of the population to respond to long-term changes in the environment, and a decrease in population resiliency (Gilpin and Soulé 1986, Lande 1988, Ralls et al. 1988, Meffe and Carroll 1994, Fitzsimmons et al. 1995, Lacy 1997). Population substructuring within a herd, as a result of female groups using distinct home range patterns, can also restrict gene flow (Geist 1971, Holl and Bleich 1983, Festa-Bianchet 1986a, Wehausen 1992, Jager 1994, Andrew et al. 1997, Rubin et al. 1998). However, relatively little genetic exchange is necessary among herds to overcome the effects of inbreeding and associated increases in homozygosity in small, isolated bighorn herds. In areas where the geographic distance between groups of adult females is small, seasonal movements of males may be sufficient to allow gene migration to occur among herds (subpopulations) within a larger metapopulation (Leslie and Douglas 1979, Witham and Smith 1979, Schwartz et al. 1986, Hogg et al. 2006). The potential for significant genetic exchange via the movements of females is low, but intermountain movements have been reported (Witham and Smith 1979, Bleich et al. 1990b, Jager 1994).

Bighorns likely evolved within a metapopulation structure, but the introduction of domestic livestock, especially sheep, into western North America, as well as other human related activities, has changed the dynamics of bighorn sheep management relative to the issues of gene flow and genetic variability. Activities designed to improve the amount of suitable habitat or to increase connectivity among habitat patches are less likely to improve population persistence than actions taken to reduce the impact of disease on bighorn sheep (Gross et al. 2000). However, Hogg et al. (2006) were able to document improvements in reproduction, survival, and other fitness-related traits by experimentally restoring immigration in a bighorn sheep population in Alberta. Attempts to increase genetic diversity in small bighorn herds in Region 2 by managing them in a metapopulation context or by augmenting sheep herds using transplants may also increase the risk associated with disease transmission among herds, which could lead to the extirpation of some small herds (Hess 1996, Dubay et al. 2003, Watkins personal communication 2005). Implementing a disease testing protocol for donor and recipient bighorn herds can reduce the potential disease risk associated with population augmentation.

Although the direct effects of competition are difficult to measure, there are data to suggest that competition with domestic livestock can influence the viability of bighorn sheep herds across their range and in Region 2. Competition with domestic sheep and goats for forage and space is a management concern in the Region, but the potential for disease transmission from sheep and goats to bighorns is a far more critical relationship. A number of domestic livestock allotments in Region 2 have been converted from sheep to cattle to reduce the risk of disease transmission to bighorns. While the conversion of these domestic sheep allotments on many national forests has been a positive step in significantly reducing the threat of *Pasteurella* epidemics, it has not eliminated the potential for disease transmission because bighorns are also susceptible to some disease pathogens associated with cattle (bluetongue) and domestic goats. It also fails to eliminate problems associated with competition from domestic livestock. Competition with domestic livestock in riparian habitats can be critical during droughts or other periods of environmental stress. Elk are potentially an important competitor with bighorns in areas where their winter ranges overlap. Heavy grazing by elk on bighorn sheep winter ranges can reduce the availability of winter forage and affect lamb:ewe ratios in the spring. Elk are a priority species in Region 2, and high population levels may play an important role in bighorn sheep management decisions in some herd units.

The following discussion is intended to provide an in-depth picture of the status of individual bighorn sheep herds within Region 2, as well as the vigor of the entire Region 2 bighorn sheep population, to the extent that information was available to the authors. It is focused on those herds found on or near National Forest System lands during at least some portion of the year. Where information was available for herds that do not use National Forest System lands extensively, the limited information available to the authors is presented. Some herds within Colorado are not discussed because detailed information was not available. The information available for these herds (or lack thereof) does not necessarily reflect their priority status within the state; rather, it is more a reflection of the time available to individual biologists to complete the summaries for each herd. The Colorado Division of Wildlife (CDOW) intends to prepare summaries for all remaining herds as time permits (Watkins personal communication 2006). Herds are examined and discussed individually and, to the extent possible, in the context of their relationship with surrounding herds. To aid in the organization of this discussion, each state was broken down by national forest, and then by individual herd or management area, as defined by the respective state wildlife management agency responsible for bighorn sheep management.

While hunting is an important source of revenue and a highly valued tradition for many residents of Region 2, it was not discussed in detail for each individual herd within the Region. This was due to the fact that although most herds support some level of harvest, it is generally at a level that has little, if any, significant effect on the conservation of bighorn sheep relative to the threats of disease and habitat loss or alteration.

Colorado

CDOW has designated bighorn sheep management units (**Appendix A**), and following that management scheme, they have recently (December 2005) completed status reports for bighorn sheep herds considered to be top priority in the state and abbreviated summaries for many other herds. Most of the following information was drawn from those reports. However, there are no current reports for a significant portion of bighorn herds within the state. The following description of bighorn herds within Colorado is organized first by national forest, then by bighorn sheep management unit within each forest. Management units that do not lie within a national forest are treated separately. Population estimates for herds that had no additional information available are provided in **Table 2**. The location of herd units that have a hunting season can be found in **Appendix A**.

Roosevelt National Forest: 1 herd

Bighorn sheep were probably native to the Poudre River Canyon. However, the current **Poudre River Herd (Unit S1)** is a reintroduced herd that was established in 1946 at a site 5 miles upstream of Rustic with 16 translocated sheep from the Tarryall Mountains southwest of Denver. In an effort to initiate range expansion, 25 sheep were translocated in 1975 from this founder population (the upper herd) to an area 7 miles downstream of Rustic (the lower herd). At least 15 sheep subsequently used this transplant area, with significant movement between the upper and lower herds (Vieira 2005). In 1991, 20 additional bighorns from Estes Park were released into the lower herd. The **Rawah Herd (Unit S18)** is adjacent to the Poudre River Herd, and the two herds interact during winter when portions of each herd use the same habitat along the Poudre River. Radio telemetry data indicate that these two herd units function as a single herd, isolated from other formally named herds. A few sheep inhabit the area north of the Poudre River unit and may rarely interact with the bighorns in units S1 and S18.

Table 2. Population estimates for Colorado bighorn sheep herds that were not discussed in the text.

Unit or Area Name	Unit Number	2005 estimate	CDOW Region	National Forest
Gore-Eagle's Nest	S2	100	NW	White River/Arapaho
Arkansas River	S7	85	SE	San Isabel
Collegiate North	S11	160	SE	San Isabel
Snowmass East	S13	110	NW	White River
Collegiate South	S17	100	SE	San Isabel
Never Summer Range	S19	25	NW, NE	Routt/Roosevelt
Snowmass West	S25	125	NW	White River
St. Vrain	S37	100	NE	Roosevelt
Basalt	S44	100	NW	White River
Brown's Canyon	S47	150	SE	Pike/San Isabel
Big Thompson Canyon	S57	80	NE	Roosevelt
Derby Creek	S59	90	NW	White River/Routt
Shelf Road	S60	150	SE	NA*
South Fork White River	S67	40	NW	White River
Cotopaxi	S68	60	SE	San Isabel/Rio Grande
Beaver Creek	S5	30	SE	Pike
Clinetop Mesa	S14	5	NW	White River
Battlement Mesa	S24	20	NW	White River/Grand Mesa
Lone Pine	S40	15	NE	Roosevelt
Cross Mountain	S45	0	NW	White River
Lower Poudre River	S58	25	NE	Roosevelt
DeBeque Canyon	NA	40	NW	Grand Mesa
Harper's Corner**	NA	40	NW	NA
Green River**	NA	90	NW	NA
Yampa River**	NA	35	NW	NA
Grizzly/No Name Creek	NA	35	NW	White River
Greenland	NA	35	NE	NA
Mount Silverheels	NA	25	SE	Pike
Mount Zirkel	NA	45	NW	Routt
Rio Grande/Box Canyon	NA	35	SW	Rio Grande
Fall River/Mummy Range***	NA	75	NE	NA
Continental Divide***	NA	100	NE, NW	NA
Never Summer Range***	NA	200	NE, NW	NA
Sawpit	NA	10	SW	Uncompahgre

*Not applicable.

**Located within Dinosaur National Monument.

***Located within Rocky Mountain National Park.

The total population of both the Poudre River and Rawah herds is estimated at 100 to 120 individuals (Vieira 2005). The herd probably has never greatly exceeded 200, was significantly reduced by a pneumonia-related die-off during 1986-1987, and has subsequently suffered low survival and lamb recruitment, at least in the lower Poudre Herd. Disease outbreaks, especially of *Pasteurella*, are the foremost threat to this herd, having already caused at least one all-age die-off. The herd also has had significant exposure to lungworm, and bluetongue has been documented in the herd unit to the south (Never Summers, Herd Unit S19). There are no public sheep grazing allotments within units S1 and S18; however, a few private citizens run domestic goats within the area of highest winter bighorn use in the Poudre River Canyon (Vieira 2005).

Habitat conditions throughout the two units are considered good, but there are concerns regarding cheatgrass (*Bromus tectorum*) invasion and juniper/mountain shrub encroachment in preferred open habitats. In addition, bighorns apparently prefer several older burns within the unit, suggesting that future prescribed burns may be beneficial. Development is not a major threat to this herd because most of its range lies within federal land. However, vehicle collisions in the Poudre River Canyon have become a significant source of direct mortality, and the threat is expected to increase as recreational use and vehicle traffic within the area continue to grow.

Arapaho National Forest: 2 herds

1) The **Georgetown Herd (Unit S32)** has fluctuated from less than 50 to over 400 during the past 60 years, and it is currently estimated at 300 to 350 (Huwer 2005). The population is stable, with an objective of 250 to 300. Few sheep inhabited the unit prior to translocations of 33 and 14 bighorns from the Tarryall Herd in 1946 and 1949, respectively. The herd subsequently increased to about 135 in the late 1950's, when the only recorded significant die-off within the unit occurred. This die-off was attributed to lungworm/pneumonia. There are currently no domestic sheep grazing allotments on National Forest System land within the herd unit, and hobby flocks of domestic sheep and goats are actively discouraged (Huwer 2005). In 1985, sheep were moved to the junction of Highway 119 and US Highway 6 to extend the range of the Georgetown Herd.

The herd is isolated from other bighorn herds, the nearest being the Mt. Evans (Herd Unit 3) Herd, only a half-mile from the boundary of the Georgetown Herd at their closest points. However, the two units are separated by Interstate 70, which sustains very high traffic volume, and Clear Creek, both of which are barriers that sheep from either herd are thought not to cross (Huwer 2005). The Colorado Department of Transportation is proposing expansion of Interstate 70 through the area to accommodate ever-increasing traffic volume. Interchange with any other herds is unlikely due to the distances that separate the Georgetown sheep from other bighorn herds.

Habitat quality is considered good, and it includes good forage quantity/quality and rough physiognomy that provides adequate escape cover. Of particular concern are the effects of development and habitat fragmentation (Huwer 2005). Much of the eastern two-thirds of the herd unit is privately owned, and the habitat is highly fragmented. The western one-third of the unit is comprised of the Arapaho National Forest, which is largely undeveloped. The fragmentation of habitat within the majority of the herd unit will continue to increase as more areas are developed. Several heavily used roads, including Interstate 70, US Highways 6 and 40, State Highway 119, and the Central City Parkway, run through this herd unit. Prior to the opening of the Central City Parkway in 2004, 12 to 18 sheep were killed annually by vehicle collisions. The level of vehicle-related mortality is expected to rise because the Parkway runs through sheep migration corridors.

Since 1986, the Georgetown Herd has been a source population for numerous bighorn translocations throughout Colorado and other states. Bighorns from this herd have gone to Nevada, South Dakota, Utah, Glenwood Canyon, Spanish Peaks, Big Thompson Canyon, Dinosaur National Monument, Browns Canyon, Durango, and Ouray (Huwer 2005). From 1986 to 2002, 280 sheep were removed from the herd for translocation.

2) The **Mt. Evans (Unit S3)** and **Grant herds (Unit S4)** interact to some extent on summer range and are therefore managed as one herd (Linstrom 2005a). The herd originated from a translocation of 16 sheep from the Tarryall herd in 1945; a second translocation of seven ewes occurred in 1948 using the same source stock. The herd generally increased during succeeding decades, reaching a high of 342 in 1996. Although no die-offs have been reported, population counts declined substantially in 2002 and 2003 (174 and 128, respectively). However, drought during that period may have influenced count conditions, as well as the actual population size (Linstrom 2005a). Lamb:ewe ratios have fluctuated greatly in recent decades, from a high of 106:100 in 1981 to 19:100 in 1998. The current ratio is estimated at 49:100, with a population estimate of 275 individuals (Linstrom 2005a).

Current and historic distributions of these two herds do not differ significantly. There are three distinct ewe/lamb groups and two distinct ram groups, centered in or near the Mt. Evans Wilderness Area, with additional use areas located in both the Arapaho and Pike national forests. Interaction with other bighorn herds is unlikely.

Disease has not significantly affected this population. However, paratuberculosis (Johne's Disease) was diagnosed in mountain goats and bighorn sheep within the unit during the 1970's, and again in 2000 and 2001 (Linstrom 2005a). While paratuberculosis is a management concern, it has been present for years and is not known to have caused significant population declines. Lungworm is also present but, likewise, has not been linked to any appreciable population-level effects.

The herd units contain abundant alpine habitat, particularly in the Mt. Evans unit, and the cliffs, boulder fields, and rock outcroppings of glacial cirques provide ample escape terrain and lambing sites. Good winter habitat is found on many of the south-facing slopes in lower elevations, which remain mostly free of snow during most years. Exotic weed invasions are not a primary concern in these herd units, as most of the sheep habitat is designated wilderness where only weed-free hay is allowed for those who use horses. Fire suppression has led to conifer encroachment in lower elevation habitats that were formerly more open, but because much of the sheep habitat is above timberline, conifer encroachment has not had major impacts on the sheep population (Linstrom 2005a).

Human recreational use is a major concern, particularly on Mt. Evans, which has a paved road that allows people to drive to the top and to access adjacent sheep habitat easily. This has led to feeding of bighorn sheep along the road, with ewes accepting handouts from tourists (Linstrom 2005a). CDOW personnel have placed salt blocks in areas to entice the sheep away from people, and they have initiated an educational program to deter people from feeding or approaching bighorn sheep and mountain goats. Other recreational impacts include hikers who leave established trails, causing sheep to move. This happens frequently near the Mt. Evans summit, prompting the USFS to design trails such that they will direct hikers away from important sheep habitat (Linstrom 2005a).

Competition between sheep and mountain goats is also a concern in these two units. A study of interactions between sheep and goats in the Mt. Evans area demonstrated that bighorns yielded space or resources to goats in 39 of 107 interactions, while goats exhibited the same response in only eight of the interactions (Reed 2001 in Linstrom 2005a). Sheep have also been known to stop using historic range in some locations after mountain goats arrived (Martin and Stewart 1977 in Linstrom 2005a).

Other concerns include winter concentrations of sheep near Grant, adjacent to Highway 285. Several bighorn sheep have been killed by vehicle collisions, as groups of sheep are often found on the shoulder of the road within a few feet of speeding traffic. Salt blocks have been placed away from the road to lure sheep out of harm's way, but with little success (Linstrom 2005a). Hazing by CDOW personnel and road signs have been used to try to remedy the situation, again with little success.

Pike/San Isabel National Forests: 13 herds

1) The **Tarryall and Kenosha Mountain bighorn herd units (Units 23 and 27)** are located adjacent to one another, with interchange (primarily of rams) between the two units. Thus, the two units are managed as a single herd (George and Davies 2005). Historically, this herd was one of the largest (over 1,000) in the state and was used extensively as a source for translocation stock from 1944 to 1953. The Tarryall/Kenosha herd is isolated from other bighorn herds, as radio telemetry data and the extent of the most recent epizootic have revealed very little, if any, interaction with other herds.

Unfortunately, this herd has a long history of disease epizootics, which have led to wildly fluctuating numbers over the past century. Epizootics occurred in 1885, 1923-1924, 1950, and most recently in 1997-1999 (Moser 1962, George and Davies 2005). Prior to the most recent pneumonia die-off, the combined population of the two herd units was estimated at 250 individuals. However, the current population is estimated at about 160 animals. In addition to disease-related mortality and the concomitant population decline, lamb:ewe ratios fell from pre-epizootic levels of 40 to 50:100 to a post-epizootic level of 0:100, and they have only increased to about 25:100 since 2002. There is no history of domestic sheep and goat allotments on public lands within the herd units, pointing to hobby flocks on private land as the probable source of exposure to pneumonia. Disease is likely to be a significant, chronic threat to this herd.

2) The **Rampart Range Herd (Unit S34)** had an interesting beginning. In 1946, a vehicle carrying 14 bighorn sheep from the Tarryalls intended for a translocation to Pike's Peak broke down near Green Mountain Falls on Highway 24. The sheep were released there and became the Rampart Range Herd. The herd grew until pneumonia/lungworm mortalities, beginning in the late 1950's, caused the herd to stagnate and decline from 40 to 20 animals by 1970. At this time, treatment for lungworm at bait stations commenced. A supplemental release of 20 sheep from Trickle Mountain in 1978 was the only other translocation into this herd. Since 1984, population estimates have varied from a high of 225 in 1990, to as few as 45 in 1995 and 1997.

The herd currently numbers 60 to 80 animals (Dreher 2005a). A total of 146 sheep have been translocated out of the herd in eight separate instances between 1984 and 2003 (Dreher 2005a).

Sheep are currently found primarily in Queen's Canyon Quarry, Camp Creek, and the areas surrounding Glen Eyrie. Historically, the overall range occupied by the herd was more substantial. Limited interchange between the Rampart Range and Dome Rock herds was documented in 2001, when a marked ram from the Pike's Peak herd was observed at the Rampart bait site (Dreher 2005a). Still, the frequency of interchange is likely low. About 1994, several sheep disappeared from the Rampart Herd. It was discovered later that some of these sheep established a small population around Greenland in Douglas County. The degree of interchange between Rampart Range and the Greenland sheep is unknown.

Disease is the primary management concern in this herd unit. In addition to the pneumonia die-off in the late 1950's, lungworm has been a concern. Antihelminthic treatment at bait sites has been ongoing since 1974, and has eliminated die-offs and contributed to some increase in the population. Because of the close proximity of these sheep to suburban Colorado Springs, domestic sheep are not a potential disease factor in the herd unit. There are no nearby domestic sheep allotments on National Forest System lands and hobby flocks are rare. There is no specific disease monitoring currently in place in the Rampart Range unit (Dreher 2005a).

Habitat quality and quantity within the unit are variable. Vegetation communities consist of mountain shrub associated with mountain-mahogany (*Cercocarpus ledifolius*), pinyon/juniper, ponderosa pine, and some manmade habitats such as the reclaimed Queen's Canyon Quarry and landscape plantings in the Glen Eyrie and neighboring subdivisions. Later stages of habitat succession have resulted in an increased area of pinyon/juniper in the unit, which has decreased visibility and the amount of available forage for bighorns. This is believed to be one major factor affecting the current distribution of the Rampart Herd; water availability is another. Habitat manipulations could increase the carrying capacity of the herd unit, and in 2002, a project was initiated to remove oakbrush from a portion of land northeast of Queen's Canyon Quarry. A guzzler was placed in the Queen's Canyon Quarry to offset a lack of available water in other areas (Dreher 2005a).

Human recreational activities, especially hikers with dogs, and development are other big factors affecting the future of the Rampart Range Herd. Both are expected to increase as development on private lands within the unit continues (Dreher 2005a). Efforts to funnel recreational activity away from sheep use-areas and to curtail development on private lands in critical areas will benefit the Rampart Range bighorns.

3) The **Waterton Canyon Herd** (no herd unit designation) is an indigenous population, occupying canyon habitat along the South Platte River in the foothills southwest of Denver. Between 1955 and 1980, the population varied from 18 (1970) to 78 (1980). During the winter of 1979-1980, construction of the Strontia Springs Dam began and likely contributed to an all-age die-off caused by stress-induced pneumonia (Spraker et al. 1984 *in* Linstrom 2005b). In addition to loss of 77 percent of the herd, the new impoundment permanently removed sheep habitat. Among the remaining 18 sheep, only one ram is known to have survived. As is typical following a pneumonia outbreak, lamb survival remained depressed for a number of years. By 1989, the herd had increased enough to allow the removal of 26 sheep for a translocation. Since that time, the herd has remained small, fluctuating between 15 and 34 individuals. It has been relatively stable for the past 10 years and is currently estimated at 25 animals (Linstrom 2005b).

The historic distribution of this herd extended from the confluence of the north and south forks of the South Platte River in the foothills southwest of Denver, to the mouth of Waterton Canyon near Denver Water's Kassler treatment facility (Linstrom 2005b). The herd may have once been part of a larger population that extended all the way to Mt. Evans, but this has not been confirmed. Currently, the herd occupies an area from just above the Strontia Springs Dam to the mouth of Waterton Canyon. Most of the sheep winter in the lower canyon below Turkshead Peak and west of the river. Lambing areas are in the upper canyon above the dam. Interaction with other bighorn herds is unlikely (Linstrom 2005b).

Disease continues to be a concern for this herd. Lungworm larvae were found in many sheep that were necropsied from the 1980 pneumonia die-off, and have been documented in several dead sheep since then. Sheep continue to be exposed to most of the same stresses that were implicated in the die-off. In addition to pneumonia, West Nile Virus was suspected as the cause for two recent ram mortalities (Linstrom 2005b).

Despite the seriousness of the threat of disease, habitat quality is the biggest concern for this sheep herd. Construction of the Strontia Springs Dam in 1980 resulted in the loss of habitat for the herd (Linstrom 2005b), permanently reducing the area's carrying capacity. Furthermore, the quality of remaining habitat has been declining due to oakbrush encroachment. In addition, the South Platte River is the only significant source of water in the area, so sheep are frequently forced to use the canyon bottom, which is heavily used by people for recreation. Consequently, it is unlikely that the herd will ever return to the pre-dam population level of 75+ animals.

Artificial water sources installed at higher elevations during construction of the dam rarely have enough water in them to be useful. Several prescribed burns and manual brush clearing were undertaken during the mid-1980's to improve visibility and forage. Periodic burning would benefit sheep by opening up habitat between the lambing area around the dam and the winter range in the lower canyon (Linstrom 2005b), but for various reasons, no habitat improvement projects have been carried out for several years. The steepness of the canyon makes burning dangerous and costly, and other methods of treatment are less efficient. Despite these concerns, habitat work may be necessary for the survival of this herd (Bailey et al. 1981 *in* Linstrom 2005b).

Other threats to the Waterton sheep are nearly as dire as disease and habitat issues. Recreational use of the canyon is high and is expected to remain so or to increase. Motor vehicle access has been restricted, but there have been numerous reports of sheep approaching people and being fed or petted. CDOW has started an education program to inform people of the problems with human/wildlife interaction in Waterton Canyon, and signs have been posted to discourage feeding or approaching wildlife. Despite these efforts and others, such as hazing by CDOW personnel, people continue to interact directly with the sheep (Linstrom 2005b).

Development, oil and gas exploration, and/or construction are also major threats to this herd in the future. Strong public opposition to a proposed development in 1987 was due in large part to concern for bighorn sheep, and it is likely that the public would also oppose any future proposals (Linstrom 2005b). Construction of more dams and roads is a potential problem for this sheep herd as well. For example, during the 1980's the Denver Water Board proposed to build the Two Forks Reservoir at the upper extent of the herd's range. Although the U.S. Environmental Protection Agency ultimately denied the permit for this reservoir, the concept remains alive. There has recently been construction activity in the lower part of the canyon during the breeding season, and more road maintenance and construction are likely (Linstrom 2005b).

4) The indigenous **Mt. Elbert Herd (Unit S66)**, currently estimated at 75 sheep, has fluctuated greatly over the past several decades. A herd of unknown size was reported in the unit in the 1940's, 42 were reported in 1956, and none were known to occupy the area in 1971 (Vayhinger 2005a). These variations in herd size and presence suggest the occurrence of periodic epizootics, but none have been documented. However, the herd has been relatively stable over the past decade, at between 60 and 75 sheep. Sheep appear to avoid areas of high recreational use within the unit, such as the climbing approaches to Mt. Elbert and Mt. Massive. During late summer and early fall, many rams from this herd also use ranges to the southwest in the White River National Forest. Private lands also fall within the typical winter range of most of the sheep, and could pose a threat to the herd if domestic sheep or goats are grazed there.

5) The **Buffalo Peaks Herd (Unit S12)** is an indigenous population that has received two supplemental translocations (29 total sheep). Both translocations occurred in 1978 in an effort to replace a lost portion of the herd that historically undertook altitudinal migrations to winter habitat (Vayhinger 2005b). This portion of the original herd was lost subsequent to construction of a water pipeline through those winter ranges in the mid 1960's. Currently, a portion of the herd displays the original altitudinal migration behavior, and the remainder of the herd resides throughout the year at lower elevations near the translocation release site.

The population size has been relatively stable over the past decade and is currently estimated at 200 individuals (Vayhinger 2005b). However, the population size has historically fluctuated between 50 (1971) and 200 (2005). An apparent disease-related die-off occurred about 1958, leading to a rapid population decline in the succeeding years and cessation of hunting between 1966 and 1976. Recreational use has affected the behavior of this herd; sheep appear to avoid areas of heavy hiker and mountain bike use near access routes to the Buffalo Peaks, Mt. Bross, Mt. Lincoln, and Mt. Democrat areas (Vayhinger 2005b).

6) The **Marshall Pass Herd (Unit S20)** is an indigenous population, ranging from 40 to 150

individuals between 1956 and 1992. Since 1992, the population has gradually decreased to the current level of 75 individuals. No releases have occurred in the unit. There may be limited interchange with the Trickle Mountain herd to the south (Vayhinger 2005c). Lambing and summer ranges are entirely on National Forest System lands in the San Isabel National Forest but are not well defined. Sheep avoid heavily used recreation areas along the Colorado Trail. This unit could support more sheep, with the limiting factor being available winter range. Winter ranges include some lower slopes along Willow and Green creeks, but very little is known of the winter habits of this population (Vayhinger 2005c).

7) It is likely that the **Grape Creek unit (Unit S49)** in south-central Colorado was historic bighorn habitat, but the indigenous population was extirpated prior to the 1900's by disease transmitted from domestic livestock and overhunting (Vitt 2005a). The current Grape Creek Herd was initiated in the 1980's through four separate translocations: 20 sheep from Trickle Mountain released in 1984, 20 sheep from the Tarryall Range released in 1985, 20 sheep from Pike's Peak released in 1988, and an additional 20 sheep from the Tarryalls released in the same year at a different location. The population flourished, growing to about 290 individuals, and is currently estimated at 225.

Sheep distribution is centered on three major areas (Hardscrabble Mountains, Grape Creek, and an area adjacent to the Arkansas River), with other, smaller isolated pockets of sheep. Interchange with sheep in the Arkansas River Herd (Unit S7) to the north is known to occur. This interchange primarily involves ram that cross the Arkansas River into Unit S7 during the rut and remain there through the end of the rut, returning to the Grape Creek Unit at the conclusion of rutting activity. Some rams may have permanently remained in the Arkansas River Unit. There is also likely interchange with the Cotapaxi Herd (Unit S68) to the west and possible interchange with the Sangre de Cristo (Unit S9) and Greenhorn (Unit S35) herds. However, large expanses of timber separate these last two herds from the Grape Creek Herd (Vitt 2005a).

No die-offs have been documented within this herd since its reintroduction (Vitt 2005a). Fire suppression in the area since the 1950's has caused a gradual decline in habitat quality, especially on winter ranges. It is hoped that changes in the San Isabel National Forest's fire suppression policy will allow some naturally ignited fires to burn and perhaps improve habitat quality for bighorns within portions of the herd unit (Vitt 2005a). Other management concerns include a unique proposal by an artist to construct a series of fabric curtains along a stretch of the Arkansas River used by a portion of the herd. The pre-construction phase of the project would take one year, followed by a 2-week viewing period attended by over a million people, and another year to remove the infrastructure. This project, if undertaken, would entail prolonged, disruptive human activity in an important area of seasonal bighorn concentration along the Arkansas River.

8) The **Pike's Peak (Unit S6) and Dome Rock herds (Unit S46)** are functionally one sheep herd consisting of 275 to 375 sheep (Dreher 2005b). Significant interchange has been documented through sightings of sheep marked on Dome Rock being observed on Pike's Peak. In addition, numerous marked Dome Rock sheep have been harvested on Pike's Peak. The herd was split into two management units in 1984 for hunting purposes, with the Dome Rock Unit established as an archery unit. Both Pike's Peak (1970-1988; 67 sheep) and Dome Rock (1995-1999; 56 sheep) have served as source populations for translocations in recent decades (Dreher 2005b).

Bear and Jones (1972) documented the historic distribution of the herd as all of the area on and surrounding Pikes Peak, the area to the west of Pike's Peak including the vicinity around Dome Rock on Fourmile Creek, and some ranges to the south of Pike's Peak. The current distribution of sheep does not differ from this historic account (Dreher 2005b). Sheep sign found in the summer of 2005 indicates that sheep also use the Almagre Mountains to the southeast of Pike's Peak. The overall range of the Pike's Peak Herd includes alpine areas above 10,000 ft. on and surrounding Pike's Peak. Concentration areas for the Pike's Peak portion of the herd include Sheep Mountain, Sentinel Point, Bison Reservoir, the sheep viewing area on the Pike's Peak Highway, Bottomless Pit, East and West forks of Beaver Creek, and Sachett Mountain (Dreher 2005b). Known lambing areas for sheep in the unit include Sentinel Point and the rugged area northeast of Bison Reservoir. Concentration areas for the Dome Rock herd include Fourmile Creek, areas around Dome Rock, Cripple Creek Mountain Estates, and Lost Canyon. In the Dome Rock unit, lambing areas include Dome Rock and the surrounding rock formations. The specific migration corridor between Pike's Peak and Dome Rock is uncertain, but it is believed to exist along Oil Creek (Dreher 2005b). In the process of migrating to the Dome Rock State Wildlife

Area, sheep must cross Highway 67, a potentially fatal undertaking that has resulted in occasional documented mortalities (Dreher 2005b).

Disease, particularly *Pasteurella* pneumonia, is the primary management concern for both units. The first documented die-off of Pike's Peak sheep occurred during 1952-53; it reduced the population from 300 to about 35 animals (Bear and Jones 1973 *in* Dreher 2005b). A herd of domestic sheep on private land adjacent to Pike's Peak was the likely cause (Bear and Jones 1973 *in* Dreher 2005b). Subsequently, the CDOW purchased property to create the Pike's Peak State Wildlife Area, presumably to create an area free of domestic sheep. The second Pike's Peak die-off, in the mid-1970's, reduced the herd by approximately 50 percent. From 1972 to 1990, wildlife managers successfully treated sheep on Pike's Peak and on Dome Rock with antihelminthics (Schmidt et al. 1979 *in* Dreher 2005b, Dreher 2005b). Although no active domestic sheep allotments are on public land in either unit, numerous landowners in the general vicinity run hobby flocks of sheep and goats, and these pose a threat to bighorns in both units. Another potential concern within the herd units includes the increasing use of domestic goats as pack animals. There is no specific disease monitoring occurring in either herd unit.

The habitat quality in the Pike's Peak unit is generally good, but late successional stages characterize much of the habitat within the Dome Rock unit. This has resulted in reduced visibility and decreased amounts of forage, making much of the Dome Rock unit unusable to bighorns. Habitat manipulations that set conditions back to earlier successional stages would benefit bighorns in this unit (Dreher 2005b).

Other management concerns include the recent large increase in recreational use, including off-highway vehicles, hiking, horseback riding, and domestic dogs frequenting sheep range, primarily within the Pike's Peak unit. Because most of the Pike's Peak unit lies within federal land, development and the associated fragmentation of habitat are not of great concern. However, much of the land surrounding the Dome Rock unit is private, and has been or likely will be developed in the future, posing a significant threat to the Dome Rock bighorns.

9) As with many other areas in Colorado, bighorn sheep were probably found in the **Greenhorn unit (Unit S35)** prior to European settlement, but were extirpated before the 20th century due to disease and overhunting. The population was re-established in 1976 with a translocation of 20 sheep from the Trickle Mountain Herd to the northern peak of Greenhorn Mountain (Vitt 2005b). The population increased to about 85 animals following release, but slightly decreased to approximately 70 animals following severe snowfall events during the winters of 2003 and 2004. The herd is currently thought to be slowly increasing. No die-offs have been documented since the herd was re-established, but lungworm has been confirmed within the population. Fenbendazole blocks have been placed in several locations on Greenhorn Mountain, with only limited use by bighorns (Vitt 2005b).

Sheep distribution within the unit is currently limited to the alpine areas of Greenhorn Mountain and burned areas on the east side, especially Apache Creek (Vitt 2005b). During periods of extreme snowfall, sheep prefer timbered cliffs along the east side of Greenhorn Mountain from the summit of the east peak to Bandito Cone near Gardner. Because of fire suppression since the 1950's, habitat quality, especially of winter range, has gradually declined. Conifers have slowly encroached on movement corridors from alpine winter ranges to lower elevation winter ranges, causing a decrease in utilization of certain winter ranges within the unit (Vitt 2005b). Sheep have started to forgo migration to lower elevation winter ranges and instead are choosing to remain in alpine areas during winter. Currently, bighorns use the North Apache Creek burn heavily, suggesting that the use of prescribed fire or the adoption of a more liberal let-burn policy would benefit the Greenhorn herd.

There may be limited, although undocumented, interchange between the Greenhorn, Mt. Maestas, and Huerfano herds (Vitt 2005b). The area between the Greenhorn and Mt. Maestas herds is not very suitable for movement between herds, but it does contain patches of lower tree density, along with scattered escape cover that could facilitate long distance movements between the two areas. Portions of the Mt. Maestas herd winter in the Black Hills area approximately 8 miles from Bandito Cone within the Greenhorn unit. Although open prairie with pinyon-juniper breaks and canyons separate the Greenhorn and Huerfano herds, the mountains that comprise the Huerfano unit are directly to the west, and it is possible that dispersing animals have come in contact with each other (Vitt 2005b).

10) The **Sangre de Cristo Herd unit (Unit S9)** encompasses portions of two national forests, the Rio Grande and San Isabel, in the Sangre de Cristo Mountains. Unlike many others within the state, this herd was never extirpated, but probably did suffer

declines prior to the 20th century due to competition with and possible disease transmitted from domestic livestock, and over-hunting. A rapid decline occurred in the 1960's and 70's that was attributed to Pasteurella/lungworm complex (Vitt 2005c), but few other disease outbreaks have been observed. The herd was one of the largest in Colorado historically, and continues to be so today, with a current estimate of 400 individuals. Only one recorded translocation into the unit has occurred; Bailey (1990 *in* Vitt 2005c) reported that 14 (1 ram, 7 ewes, and 6 lambs) sheep from the Tarryall Range were released to supplement the existing herd in 1945. Historically and presently, the population has been centered on three areas: Medano Pass, Sand Creek, and the area between Kit Carson and Horn peaks (Vitt 2005c). Some interchange may occur with the Huerfano bighorns (Unit S8) in the southern Sangre de Cristo range, but interchange with any other bighorn herds is unlikely. Because of the remoteness of the habitat, sheep have not been treated with Fenbendazol (Vitt 2005c). No information was provided regarding the threat of domestic sheep grazing in the area.

Habitat quality is becoming an increasing concern within the herd unit. Since the 1950's, fire suppression has detrimentally affected habitat quality, particularly winter range (Vitt 2005c). Conifer encroachment into migration corridors has caused a decrease in utilization of certain wintering areas, and some sheep no longer migrate to lower elevation winter ranges. As with other herd units, increasing human recreation has become a management concern. Individual drainages within the area routinely see as many as 85 recreationalists per day during peak times.

11) The **Huerfano Herd (Unit S8)** occupies the southern end of the Sangre de Cristo Mountains, and it likely forms a metapopulation with the Sangre de Cristo and Costilla bighorn herds. The Huerfano Herd has been relatively productive although six to eight dead sheep were documented in the late summer of 2005 (Wait 2005a). Some of these deaths may have been due to lightning strikes. The herd is currently estimated at 65 individuals. No information regarding disease or domestic sheep was available to the authors.

12) The **Costilla Herd (Unit S65)** is not located on USFS land, but is adjacent to the San Isabel National Forest. This herd may have been created by a transplant of 34 bighorns from British Columbia onto the Forbes Ranch in 1990, or that transplant might have been an augmentation to existing herds in the area (Wait 2005a). In either case, the Costilla Herd has been quite productive and is currently estimated at about 400 sheep. Most of the herd ranges throughout the Trinchera Creek drainage on the Forbes Ranch, but it is also connected to the Culebra Herd unit (Unit S51) east of the southern end of the Sangre de Cristo Mountains. No information regarding disease outbreaks or domestic sheep grazing was available to the authors.

13) The **Culebra Herd (Unit S51)** is an introduced herd that has received many translocations. The initial translocation involved releasing an unknown number of sheep from an unknown source onto the Spanish Peaks State Wildlife Area. The bighorns promptly moved and established a small herd in Mauricio Canyon west of Aguilar (Vitt 2005d). Three additional translocations from 1984 to 1989 involved releasing 65 bighorns into different areas throughout the herd unit. The source populations for these sheep were the Queen's Canyon Quarry (20 sheep), Georgetown (20 sheep), and the Almont Triangle (25 sheep). Some of the sheep from these translocation efforts did not remain near their release sites, but the population within the herd unit has done well and its currently increasing population is estimated at about 250 individuals (Vitt 2005d).

Sheep inhabit the West Peak of the Spanish Peaks and the Culebra range of the Sangre de Cristo Mountains from Stateline Peak on the New Mexico State line north to Napoleon Peak (Vitt 2005d). Summer range for this herd is alpine meadows and associated timberline habitat, while winter range includes the 14,000 ft. summit of Culebra Mountain to the cliffs and aspen-covered mountainsides around North Lake. Sheep from West Peak also winter from above timberline to the volcanic dikes that radiate out from the summit, to the lower elevation hillsides near La Veta (Vitt 2005d).

Interchange with other sheep herds has been documented through observations of reintroduced animals in other herd units shortly after being transplanted into the region. Most of the interchange has been with the Mt. Maestas Herd, with several bighorns from three different translocations leaving the Culebra Herd and becoming established there (Vitt 2005d). In addition, because both the Culebra and Costilla sheep share the same mountain range, there is interchange between these two herds. Another potential area of interchange is with the Huerfano Herd (Unit S8), but an expanse of timbered habitat provides a barrier to movement between these units (Vitt 2005d).

Public access to this herd for hunting is restricted because of the extensive private holdings within the unit. In addition, there is the serious threat of

Pasteurella pneumonia exposure and related die-offs because recent court rulings allow the reintroduction of domestic sheep into the Cielo Vista ranch (Vitt 2005d). Monitoring of fecal lungworm loads within the herd began in the summer of 2005, but CDOW has not yet received results of this study (Vitt 2005d).

Other management concerns include development in the Cordova Pass area, where expected increases in development will likely curtail or even prevent interchange between the West Spanish Peak sub-herd and other sub-herds within the unit (Vitt 2005d). In addition, because public land is restricted within the herd unit, it is expected that increases in human recreational activities such as mountain climbing will negatively affect bighorns in publicly owned areas inhabited by sheep.

Habitat quality is generally very good within the herd unit, but increasing bighorn sheep and elk populations are producing negative impacts. The elk population in this unit is 4,000 animals over objective, and the limited bighorn harvest has led to concerns of overpopulation (Vitt 2005d). Fifty years of fire suppression has also caused a slow decline in the quality of winter range. Resulting conifer encroachment in migration corridors from high to low elevation winter ranges may decrease utilization of certain winter ranges within the unit, with some sheep foregoing migration to lower elevation winter ranges altogether (Vitt 2005d).

Rio Grande National Forest: 4 herds

1) The **Natural Arch Herd (Unit S55)**, currently estimated at 20 individuals, has been in continued decline over the past several years, likely due to chronic exposure to diseases from domestic sheep (Wait 2005a). Lamb recruitment is very low, and the future of the herd looks bleak. Hunting was closed within the unit in 2006 because hunters have not been successful in finding legal rams and have reported no observations of bighorns in the past few years (Wait 2005a).

2) The **Bristol Head Herd (Unit S53a)** is currently a stagnant herd estimated at 50 individuals. This herd faces probable contact with domestic sheep, but this has not been conclusively documented (Wait 2005a). The sheep within this unit were probably once part of a larger population with surrounding herds, but no interchange currently occurs.

3) The **Pole Mountain/Upper Lake Fork Herd (Unit S33)** occurs in both the Gunnison and Rio Grande national forests. See Gunnison National Forest section for a discussion of this herd unit.

4) The **Alamosa Canyon and Conejos herds (Units S29 and S30**, respectively) would likely serve as a metapopulation along with the Blanco River/Navajo Herd, but exposure to domestic sheep is probably the limiting factor keeping them segregated in isolated herds (Wait 2005a). The Conejos Herd, estimated at about 75 sheep, is in jeopardy of exposure to domestic sheep throughout the Conejos drainage. There have been no documented die-offs in the Conejos Herd, but the Alamosa Canyon Herd did experience a die-off in the late 1980's/early 1990's. The Alamosa Canyon Herd, estimated currently at about 35 sheep, has had extensive exposure to domestic sheep grazing in the Alamosa and Conejos River basins (Wait 2005a). While these herd units contain vast areas of very good bighorn habitat, they will probably continue to be limited by exposure to domestic sheep grazing (Wait 2005a).

San Juan National Forest: 5 herds

1) The **Vallecito Creek Herd (Unit S28)** is a native herd currently comprised of about 125 bighorns; this is larger than it has been in most of its recorded past (there were an estimated 30 to 50 sheep in both 1973 and 1988). The only recorded translocation into the herd occurred in 1988 and involved 20 sheep from the Snowmass unit. This translocation was undertaken to increase the genetic diversity and vigor of the herd, but it was considered unsuccessful based on the subsequent performance of the herd (Wait 2005b). No interchange with other bighorn herds exists.

Domestic sheep were commonly grazed and trailed through this herd unit until 1990, and this may have resulted in the translocation failure. At that time, a conflict between domestic and bighorn sheep was recognized, and the USFS changed the allotments from domestic sheep to cattle and horse grazing. *Pasteurella* has not been isolated from any of the sheep within the unit (Wait 2005b). Recreational use and development are thought to be minimal threats to this herd (Wait 2005b).

Vallecito Creek bighorns use two distinct habitat types. Most of the herd winters at lower elevations characterized by scattered trees within large rocky outcrops, where reduced sight distances may be a constraint for sheep by increasing their vulnerability to predators. This area also appears to serve as lambing habitat. Other sheep use the alpine areas year round; however, extreme snowfall events in alpine areas dramatically limit the availability of habitat in some winters (Wait 2005b).

2) **The Cimmarona/Hossick Herd (Unit S16)** is a native herd, currently estimated at about 100 to 125 individuals and experiencing reasonable lamb production and recruitment (Wait 2005c). It has expanded from the 30 to 40 sheep found in the herd from 1944 to 1970 (Bear and Jones 1973 *in* Wait 2005c). This herd is isolated from other bighorn herds, and no records of translocations into or out of this herd are known (Wait 2005c).

Disease, particularly *Pasteurella*, is a moderate concern for this herd (Wait 2005c), but it has not been isolated from any sheep. Domestic sheep were commonly grazed and trailed through this bighorn herd until 1991, when the allotment was changed from domestic sheep to cattle and horses. All grazing of domestic stock has since been eliminated (Wait 2005c).

Most habitats within the unit are in good or excellent condition. Winter range is somewhat restricted, particularly following big snowfalls (Wait 2005c). Frequent avalanches appear to maintain access into the Williams Creek drainage, which may have allowed recent expansion into this area. Recreational activity, development, and habitat fragmentation are not major threats to this herd, primarily due to the steep and remote terrain.

3) The history and status of the **Sheep Mountain Herd (Unit S15)** are nearly identical to those of the Cimmarona/Hossick Herd described above. Domestic sheep were commonly grazed and trailed through this herd unit until the mid 1970's in the Sheep Mountain area and until 1991 in the Turkey Creek and Deadman areas. The allotments were then changed from domestic sheep to cattle and horses, and then grazing of all domestic stock was eliminated (Wait 2005d). The herd is currently estimated at 100 to 125 individuals.

4) The history and status of the **Blanco River/ Navajo Herd (Unit S31)** are nearly identical to those of the Cimmarona/Hossick and Sheep Mountain herds described above. The biggest difference is that disease, particularly *Pasteurella* pneumonia, is a relatively high management concern for this unit (Wait 2005e). Domestic sheep were commonly grazed and trailed through this herd unit until the mid 1970's in the Fish Lake area and until 1989 in the Elwood Pass area. At that time, a conflict between domestic and wild sheep was recognized, and the allotments were changed from domestic sheep to cattle and horse grazing. All grazing of domestic stock has since been eliminated (Wait 2005e). The east side of the Continental Divide is still open to domestic sheep grazing and is regularly grazed, creating the potential for contact between bighorn and domestic sheep. The herd is currently estimated at 100 to 125 individuals.

5) The **Animas Canyon Herd** (no herd unit designation) was established with animals translocated from the Georgetown Herd in 2000 and 2002-2003. The population is currently estimated at 70 animals, and reproduction and survival have been good in each year since then (Wait 2005a). Sheep use the entire Animas Canyon from Rockwood up to Needle Creek, with primary summer range being the Twilight/West Needles area, and primary winter and lambing range in the Animas Canyon from Rockwood up to the Cascade Wye. Immediately after release, two bighorns dispersed into the Cow Creek herd unit, where one was hit by a car and killed, and the other joined the Cow Creek animals. Based on ear tag observations, several sheep dispersed into the Lake Fork/Pole Mountain herd, and six or seven sheep moved into the Hermosa Cliffs area, where they have remained and have produced lambs every year (Wait 2005a).

Gunnison National Forest: 8 herds

1) The **Taylor River Herd (Unit S26)** historically included two independent sheep herds, the Taylor River and Fossil Ridge herds. Based on seasonal habitat use and migration patterns, CDOW recognized that these two herds were independent of one another and divided them into separate management units (Units S26 and S70) beginning in 2006. There are various bighorn sheep herds residing within close proximity to the Taylor River herd, including S11, S13, S54, and for 2006, S70. Although exchange is now rare between these herds, it is possible that they once formed a larger metapopulation. Due to several factors, however, the lack of sufficient connectivity does not currently permit significant exchange between different herds.

The Taylor River herd is comprised of approximately 75 animals (Diamond 2005a), down from a recent high of about 131 animals in the late 1990's. Within the past 3 to 4 years, the herd has experienced very poor lamb recruitment, which has led to the population decline. This herd has experienced at least three significant die-offs over the last 40 years: 1961, winter 1978-79, and winter 1991-92. The most severe die-off occurred during 1978-79, when the population declined by an estimated 75 to 80 percent. These die-offs have been attributed to three primary factors: stress, competition for limited winter forage, and lungworm parasitism. Stress factors include severe winters, drought, human disturbance, or years where sheep experience unusually high lungworm burdens. Prolonged periods of high stress may predispose bighorn sheep to infection by various disease pathogens. Recent analysis of the average maximum sustained cortisol concentration (AMSCC) in the Taylor River bighorns indicated that this herd may have been subject to high stress levels. AMSCC values were obtained from Taylor bighorns on at least six different occasions, and with the exception of 1988, AMSCC values indicate a highly stressed herd during all years sampled (Diamond 2005a).

Cambendazole and Fenbendazole have been administered to Taylor River sheep on bait stations since the late 1970's (Diamond 2005a) with the intention of minimizing lungworm burdens and reducing the risk of pneumonia infection. Medical treatment at bait stations has been the subject of considerable debate among wildlife researchers because it is generally not possible to administer the appropriate dosage to each individual animal. Costs are high for medication and maintaining a bait station, and there are concerns about concentrating bighorns at bait sites because it may foment the spread of disease. Although the Taylor River bighorn herd has not been medicated in recent years, CDOW intends to distribute Fenbendazole blocks throughout winter and transitional ranges in 2006. These medicated blocks may provide some relief from lungworm parasitism while minimizing concentration at a single bait site (Diamond 2005a).

Habitat quality in the herd unit is considered good. The unit contains reasonably large blocks of habitat with decent connectivity between seasonal ranges. Summer forage conditions in high-elevation alpine habitats are excellent, and critical, lower elevation winter ranges provide a diversity of forage and escape terrain. However, heavy winter browsing by ungulates has likely reduced plant vigor, and therefore, forage quality may not currently be optimal. Conifer encroachment and an increase in cheatgrass are of concern in the Almont Triangle area, presenting another management concern on already limited winter ranges. Plant community succession, particularly on transitional ranges, is also of concern in this unit (Diamond 2005a). Other significant concerns facing this herd include increased recreational use and development in critical transition ranges.

2) The **Fossil Ridge Herd (Unit S70)**, as mentioned previously, was formerly included with the Taylor River Herd for management purposes, but as of 2006, it is managed as a separate herd. This herd was initiated in the winter of 1992 with a translocation of 20 bighorns from the Trickle Mountain Herd, and it is currently estimated to contain 60 individuals. Lamb recruitment has been moderate during most years but has recently declined and may lead to an overall population decrease. Winter range is extremely limited for this population and may represent a bottleneck (Diamond 2005b). As mentioned earlier, there is little interchange between the Fossil Ridge Herd and surrounding bighorn herds.

3) The **West Elk and Dillon Mesa herds** are distinct herds but comprise one herd unit for management purposes (Unit S54) (Diamond 2005b). The indigenous West Elk population inhabits the alpine habitats within the West Elk Wilderness, and the translocated Dillon Mesa population generally inhabits the area north of Blue Mesa Reservoir at lower elevations.

The West Elk sheep remain in alpine habitats year-round, but some exchange is suspected with the Dillon Mesa population, particularly between ram groups. Historically, the West Elk Herd probably inhabited a much larger area than it does currently. The West Elk bighorn herd has experienced regular population fluctuations common to many other bighorn herds within Colorado, but it has demonstrated remarkable resiliency over the last century. The herd appears to have declined by about 50 percent over the last 10 years and conservatively consists of 50 to 60 animals today. This herd has never received a transplant nor been used as a source herd (Diamond 2005b). Stress factors including winter severity, forage quality, and lungworm burden have all likely exerted an influence over annual survival and recruitment rates in this population (Diamond 2005b). It is unknown whether these herds are likely to encounter domestic sheep.

Bighorns were likely indigenous in the area currently inhabited by the Dillon Mesa population, but they were extirpated following European settlement. Reintroduction efforts began in the 1970's with the release of 25 sheep from the Trickle Mountain herd. This was followed in 1977 by the augmentation of an additional 19 sheep from Pike's Peak. The initial population flourished but experienced a catastrophic die-off during the severe winter of 1983-84. Twenty-five additional sheep were translocated during 1996 and 2000 to supplement the dwindling herd. Since that time, lamb recruitment has been poor during most years, with stress and disease suspected as the primary limiting factors (Diamond 2005b). Highway 50 has been a significant mortality source for this population, with numerous documented road-kills. Efforts (i.e., guzzler installation, salt blocks) to keep sheep off the highway have been largely unsuccessful. This herd exhibits seasonal movement between suitable habitats, and some exchange of rams with the West Elk bighorns is suspected in the upper reaches of West Elk Creek (Diamond 2005b).

4) The **Lower Cochetopa Canyon Herd (Unit S69)** originated from two translocations in 1995 and 1996 of 32 sheep from the Taylor River Herd. Translocated animals initially flourished, but lamb recruitment has been poor since the early 2000's. The Lower Cochetopa Canyon population is currently estimated at 55 animals. Sizeable tracts of habitat exist throughout the canyon; however, drought, road-kill, disease, and predation appear to hinder the vigor of this herd. Fenbendazole blocks have been periodically distributed throughout Cochetopa Canyon, but it is difficult to assess their level of effectiveness in preventing disease (Diamond 2005b). The herd prefers to range within close proximity to Cochetopa Canyon, which provides escape terrain (Diamond 2005b); therefore, interchange with other bighorns herds is likely limited.

5) The **Trickle Mountain Herd unit (Unit S10)** encompasses area in both the Gunnison and Rio Grande national forests. This unit was once one of the most productive herds in Colorado and a source for translocation stock for many other herds (Wait 2005a). The herd numbered as many as 400 to 500 in 1993 but suffered a catastrophic die-off in 1993-94. The population subsequently crashed to the current number of about 50, and it has exhibited very low lamb recruitment ever since. Domestic sheep were grazed on the edge of bighorn range in 1993 and were the likely the source of exposure to disease. The specific disease that led to the die-off was never positively identified (Wait 2005a). There are no currently active domestic sheep allotments within this herd unit.

6) Bighorns within the **San Luis Peak Herd unit (Unit S22)** are a native population that was never extirpated (Diamond 2005c). The current population estimate is 80, and there have never been any translocations into or out of the herd. The herd is centered close to the La Garita Wilderness and surrounding areas, which are considered to constitute critical bighorn habitat. Historically, there was overlap between the lower elevation winter ranges of San Luis sheep and the overall range of the Cebolla Creek/Rock Creek Herd (Unit S52) inhabiting the Cebolla Creek drainage. Some records indicate that bighorns in these two units were essentially one herd (Diamond 2005c). It is probable that what are currently designated as two distinct herd units historically made up one larger population, which was fragmented following population reductions that occurred during European settlement. There are three bighorn sheep herds residing within close proximity to the San Luis Unit: the Rock Creek (Cebolla) Herd primarily occupies Cebolla Creek and adjacent drainages that lie to the north, and the Bellows Creek and Bristol Head herds reside to the south and southeast of the San Luis unit. It is possible that these areas once sustained a large, freely exchanging population. However, no regular interaction has been documented during recent years (Diamond 2005c).

San Luis sheep often spend the entire year in alpine habitats, but some migrate to lower elevations during winter. Sheep that remain in the alpine during winter utilize slopes with southern aspects and windblown ridges where forage is available, while those that migrate to lower elevations use the broken terrain available in the lower reaches of the Spring Creek drainage (Diamond 2005c). Historically, sizeable groups of rams migrated from the high country into the Cebolla Creek drainage during winter where they would undoubtedly encounter sheep from the Cebolla Creek population. However, the Cebolla Creek Herd experienced a significant *Pasteurella* related die-off in the early 1990's (Diamond 2005c). Subsequently, large groups of rams were no longer observed in the Cebolla drainage. It is likely that ewe and lamb groups also historically migrated in the Cebolla Creek drainage during winter; however, recent monitoring indicates that sheep from the San Luis no longer use the Cebolla Creek drainage during any time of the year (Diamond 2005c).

Domestic sheep allotments are still active in portions of the unit, and domestics were observed during the summer of 2005 in very close proximity to bighorns. Without significant modifications to the existing grazing regime and/or closure of specific allotments within bighorn range, future die-offs are likely. No disease monitoring has ever occurred in the San Luis unit, nor have the sheep ever been treated with Fenbendazole (Diamond 2005c).

Large blocks of quality habitat exist throughout the San Luis unit, with good connectivity between seasonal ranges (Diamond 2005c). High-elevation alpine habitats provide excellent forage during the summer months and are interspersed with cliffs and rocky outcrops critical for lambing and escape. At lower elevations, broken, south and west facing slopes provide additional winter ranges complete with abundant forage and escape terrain (Diamond 2005c). The primary habitat concern in this unit is conifer encroachment, especially in lower elevation winter ranges.

Another potential threat to the overall health of the San Luis Herd is increased recreation. Bighorn sheep show strong fidelity to certain areas within the unit, and the potential for conflict will escalate as human recreational use increases. There is a significant amount of off-highway vehicle use year-round to the south of the La Garita Wilderness, and snowmobile disturbance during winter months is of concern to wildlife managers (Diamond 2005c).

7) Occurring in both the Gunnison and Rio Grande national forests, the **Pole Mountain/Upper Lake Fork Herd (Unit S33)** is likely an indigenous herd that received two small supplemental transplants totaling five sheep in 1987. Three of these translocated animals were from the Trickle Mountain Herd, and two were from the San Luis area (Diamond 2005d). The herd currently numbers about 60 animals, but because the unit contains large expanses of suitable bighorn habitat, it may have supported a larger herd in the past. Historically, there were three sub-populations within the unit, described as the Pole Mountain, Lake Fork, and Henson Creek sub-herds. Sheep still inhabit these traditional areas, occupying alpine habitats year-round, but typically concentrating above tree line after winter snows have receded and new forage becomes available. During winter, many of these sheep migrate to lower elevations in the broken, south-facing slopes available of the Lake Fork and Henson Creek drainages. Sheep have also been observed below Rio Grande Reservoir during the winter months.

The San Luis Peak (S22) and Bristol Head herd units (S53) are situated to the east of the Lake Fork Herd across Highway 149, the Cow Creek (S21) Herd is immediately adjacent to the northwest, and the Animas Canyon Herd resides immediately to the southwest of the unit. Although undocumented at this time, there may be periodic interchange with units S22, S53, but it is likely minimal due to large, intervening expanses of forest. Exchange with the Animas Canyon Herd has been documented, and exchange with animals in Cow Creek is likely based on their proximity and the availability of movement corridors (Diamond 2005d).

An apparent die-off occurred in the late 1980's, causing a population decline that prompted the closure of hunting in 1991 (Diamond 2005d). During an aerial survey in 1988, three of four radio-collared sheep were found dead in different locations throughout the unit, suggesting that a widespread die-off had occurred. At least five bands of domestic sheep were seen across the unit during the survey. Hunting was reinstated within the unit in 2006, with a harvest quota of 2 rams. Domestic sheep grazing has historically occurred throughout the herd unit, and four allotments are currently active. Continued domestic sheep grazing is a primary concern to managers, as some active allotments are situated on the boundary between the Lake Fork and the Cow Creek herd units, posing a severe risk of disease transmission to bighorns in both herds. No specific disease monitoring has occurred in the Lake Fork Herd unit, and the herd has never been treated with Fenbendazole. CDOW attempted to trap sheep in the Lake Fork unit during the winter of 2005-2006 to obtain biological samples for disease testing, but was unsuccessful due to interference by elk at the bait site (Diamond personal communication 2007).

Habitat quality in the unit is excellent. Large blocks of high quality habitat are distributed throughout the unit, with good connectivity between seasonal ranges (Diamond 2005d). Summer ranges include alpine habitats containing excellent forage and juxtaposed with cliffs and rocky outcrops that provide critical lambing and escape terrain. At lower elevations, broken, south-facing slopes provide critical winter range with abundant forage and escape terrain (Diamond 2005d). Plant community succession is of concern, particularly on winter ranges. Conifer encroachment, particularly in traditional bighorn use areas, will become an increasing threat if not addressed through management action. In addition, large herds of elk and deer inhabiting this unit could cause competition for space and resources, but this is not now considered a limiting factor for bighorns (Diamond 2005d).

Other concerns for the Lake Fork Herd include increased recreational use. Hiking, biking, camping, hunting, fishing, wildlife watching, cross-country skiing, and off-highway vehicle use are some of the activities taking place in the herd unit. Although much of the area is remote, bighorns in the unit tend to show a strong fidelity to certain areas, creating the potential for conflict as human use escalates in those areas. Areas of particular concern are along the Alpine Loop west of Lake City, and the Lake Fork drainage above Lake San Cristobal, where continuous recreational disturbance could lead to displacement of sheep into suboptimal habitats. In addition, development is considered a great threat to resident sheep in certain areas. Much of the private land above Lake San Cristobal is continuously being developed. Construction near the river bottom and on the north side of the valley is occurring in areas used by bighorns during the winter months, and decreasing winter range availability may represent a potential bottleneck for herd productivity (Diamond 2005d).

8) The **Rock Creek Herd (Unit S52)** is likely indigenous and represented an extension of the San Luis Peak sheep herd (Diamond 2005b). A translocation in 1977 was "intended to increase the distribution and population of bighorn sheep adjacent to existing concentrations" (Bear 1977 *in* Diamond 2005b). This translocation initially did quite well, and the Rock Creek Herd was soon used as a source herd for transplant stock. The herd then suffered a severe die-off during 1989-1990 that was believed to have also affected the San Luis population. Additional translocations were carried out in 2002 to supplement the declining population. The herd is currently estimated at only 20 to 25 animals, and it primarily inhabits the Cebolla and Rock Creek drainages southeast of the town of Powderhorn (Diamond 2005b).

Large tracts of habitat exist within the herd unit, but chronically low levels of lamb recruitment apparently hinder population growth (Diamond 2005b). During 2002, three bighorn ewe carcasses were discovered; these animals had apparently died of pneumonia (*Mannheimia hemolytica*). In addition, Bovine Viral Diarrhea Virus (BVDV) was isolated from the lung tissue of one of these ewes. Disease is likely the greatest limiting factor for this herd (Diamond 2005b).

Uncompahgre National Forest: 1 herd

The **Ouray-Cow Creek Herd (Unit S21)** is somewhat unique in Colorado as it is one of the few remaining indigenous herds (Banulis 2005). In the early 1900's, this herd was estimated at about 1,000 individuals. The first drastic decline in the herd occurred in 1923, when mining activity and housing development reduced critical winter range, and disease from domestic livestock infected the herd. The size of the herd remained depressed over the next several decades, estimated at 150 to 200 in the late 1970's (Banulis 2005). In 1983, lungworm and pneumonia were the likely causes of low lamb recruitment and another population crash to about 40 animals four years later. The herd gradually increased to about 80 by the mid 1990's, and contains 100 head currently.

Three translocations have been associated with the Ouray Herd. Two of these were out of the herd and were conducted with the primary purpose of reducing the Ouray population and the potential spread of disease. The first translocation occurred in 1983 and involved 19 sheep being relocated to the Bristol Head Herd, while the second occurred in 1985, with 20 sheep moved to Brown's Canyon. The single translocation into the Ouray Herd occurred in 1992, when 21 bighorns from the Georgetown Herd were released into Cutler Creek (Banulis 2005).

Mining development within the herd unit began in the late 1800's. Prior to this time, bighorns wintered throughout the area currently occupied by the town of Ouray and on benches in the Uncompahgre Valley between Ouray and Ridgeway (Banulis 2005). As development increased, the herd's winter range decreased. The Ouray-Cow Creek Herd currently winters in significantly smaller patches of habitat within the same area as they did historically. Current wintering areas include benches along the Uncompahgre River Valley near Ouray downstream to Dexter Creek, Cutler Creek, and to East Baldy Peak. Many sheep also winter above 9,000 ft. in areas that are open, south-facing slopes in close proximity to rugged volcanic tuft outcrops (Banulis 2005). Historic summer distribution probably occurred in the areas that are currently used, and included the upper elevations of the Cimarron, Cow Creek, and Uncompahgre River drainages (Banulis 2005). Historically, the Sneffles Range west of Ouray was probably used much more extensively as summer range than it is now.

There is possible interchange between Ouray bighorns and sheep in the Lake Fork (Unit S33) and/or Animas herds (Banulis 2005). Two radio-collared sheep from the Animas Herd have been located within the Ouray/Cow Creek Herd unit in association with Ouray bighorns. If these herds increase, it could lead to increased exchange of individuals, especially of dispersing juveniles (Banulis 2005).

Disease, particularly *Pasteurella* pneumonia, is the primary management concern for the Ouray/Cow Creek Herd. *Pasteurella* and lungworm were determined to be the causes for a drastic population decline during the early 1980's. Similar occurrences prior to the 1980's have also been recorded (Banulis 2005). To deal with the disease threat from 1979 to 1985, bighorns were trapped and treated for lungworm with Fenbendazole, then released within the Ouray area to reduce lungworm loads and to minimize the potential for a *Pasteurella* die-off. As mentioned previously, 39 sheep were also trapped and transplanted out of the Ouray herd to reduce the population and winter concentrations in an attempt to minimize the spread of lungworm and *Pasteurella*.

Fenbendazole blocks were occasionally distributed in wintering areas during the 1980's and 1990's (Banulis 2005). Currently, there is no specific disease monitoring occurring within the herd unit, other than necropsy and testing of animals that are hit by cars (Banulis 2005). Several domestic sheep allotments occur within the Ouray/Cow Creek Herd unit. Although most allotments have not been active in recent years, there has been a growing interest in restocking these allotments.

Habitat quality within the unit is considered good. The rough terrain provides necessary escape cover, and forage quantity and quality generally appear adequate. The primary habitat concerns in this unit are the loss of disturbance-free wintering areas, increases in spruce and oak brush, and availability of suitable forage due to competition with domestic livestock (Banulis 2005). Wintering sheep are now restricted to small benches that are undeveloped or developed in low densities. These are increasingly threatened by ongoing fire suppression, which has allowed oak-brush stands to dominate formerly suitable sheep habitat. In 1989, 800 acres of oak scrubland were burned to increase available bighorn habitat, and fertilization treatments to improve forage vigor have been conducted. Competition with domestic livestock has been a concern for at least 70 to 80 years, when accounts of district rangers noted that large portions of the area were not suitable for bighorns because of domestic livestock grazing. Declining numbers of domestic livestock have likely reduced competition in recent years; however, competition with other wildlife species, particularly elk, could be a threat to bighorns as both deer and elk densities are moderate to high within the herd unit (Banulis 2005).

Other management concerns for this herd include increased recreational use. Increasing numbers of hikers, dogs, horseback riders, off-highway vehicle and 4x4 enthusiasts, and mountain bikers are a major threat to the continued persistence of the Ouray/Cow Creek bighorns. The greatest concern is disturbance by recreationalists and domestic dogs during winter months when bighorns are concentrated and stressed (Banulis 2005). Traditional bighorn wintering areas occur on private land, which faces heavy development pressure. In addition, Highway 550 poses a significant threat to bighorn sheep during seasonal movements, and a few sheep are killed in vehicle collisions each year. Although mining activity in the area has decreased significantly within the last 20 years, a new gold mining operation is planned in the Uncompahgre Wilderness in the West Fork of the Cimarron drainage (Banulis 2005). Equipment, personnel, and ore will be transported to and from the mine using daily helicopter flights. The impact of this operation on sheep in the herd unit is unknown but could be significant.

Other herds in Colorado on or near National Forest System land: 7 herds

1) The **Apishapa Herd (Unit S38)** was initiated in 1977 with a translocation of 25 sheep from the Upper Poudre River Herd. An additional four rams from the Collegiate North Herd were released into the unit in 1990 (Vitt 2005e). The population subsequently increased to 100 individuals by 1984, declined to about 40 by 1988, and has since held at about 80 animals.

Bighorns inhabit the main and side canyons of the Apishapa River Canyon, from the Cross Canyons/Apishapa River junction downstream to South Canyon. Lambing areas are located upstream of the confluence of Jones Lake Canyon and the Apishapa River. Rams are found in South Canyon during the non-breeding season and move to the Apishapa State Wildlife Area during the breeding season. There is likely no interchange with other bighorn herds, as considerable expanses of short grass prairie separate this population from others (Vitt 2005e).

The threat of disease to bighorns in this unit is mostly unknown. No large die-offs have been reported, and fecal lungworm loads were evaluated once (at an unknown time) and found to be very low (Vitt 2005e). Habitat quality has remained good since sheep reintroduction, but continued fire suppression and noxious weed invasions may reduce habitat quality in the future. Human recreation and development are not of concern to sheep in this unit (Vitt 2005e).

2) The **Purgatoire Canyon Herd (Unit S61)** was initiated in 1982 with the translocation of 17 bighorns from the Never Summer Range in Rocky Mountain National Park into the Purgatoire River Canyon. A subsequent translocation was made in 1986 using 20 sheep from the Collegiate North Herd, which were released into Chacuaco Canyon, a major tributary canyon of the Purgatoire. The herd increased to an estimated 240 individuals by 1996 and has remained at about that level up until the present (Yost 2005a).

Bighorns are distributed throughout much of the main Purgatoire and Chacuaco canyons. The greatest numbers occur on the south side of the Purgatoire, with many small bands of sheep inhabiting side canyons such as Bruno, Tobe, and Poitrey (Yost 2005a). The Pinyon Canyon Military Reservation on the north side of the Purgatoire River also supports good numbers of sheep. Because of the low elevation of this herd unit, sheep make minimal or no seasonal movements. For several years, bighorns have been absent from portions of the canyon near the Comanche National Grassland and Army property boundary. However, recent reports from landowners indicate that sheep are beginning to return to this area. It is not known why they disappeared for several years, but lungworm is suspected (Yost 2005a). In 2000, sheep hunters reported numerous sheep with severe coughing and poor body condition, and one sheep was harvested that exhibited symptoms of pneumonia. However, lung tissue samples from the ram indicated that lesions on the tissue were caused by a lungworm infestation. There have been no other disease concerns, nor is there any specific disease monitoring occurring within the herd unit (Yost 2005a). No interchange with other bighorn herds is thought to occur due to several miles of shortgrass prairie between the Purgatoire sheep and the nearest bighorns in the Carrizo (S48) and Apishapa (S38) units.

Habitat quality within the unit is considered good. High, rocky canyon walls provide excellent escape cover, and the diverse vegetation offers quality forage (Yost 2005a). Nevertheless, Yost (2005a) suggested that burning could further improve forage quality. Tamarisk (*Tamarix parviflora*) is encroaching in some of the drainages, and Pinyon-juniper has encroached over much of the area; both are situations that could be remedied through mechanical treatment or fire. Human recreation and development are not of concern to sheep in this unit (Yost 2005a).

3) Twenty bighorn sheep from the Collegiate Range were translocated to private property at the confluence of Cottonwood and Carrizo creeks in 1980, initiating the **Carrizo Creek Herd (Unit S48)**. The herd doubled in size by 1985 (Yost 2005b) and has stabilized at about 50 individuals since the early 1990's. Current bighorn distribution is centered in the West Carrizo Creek area (Yost 2005b). Breeding generally occurs on or near the Mizer rye fields, with lambing occurring in the canyons above. Since the highest mesa tops are less than 1,830 m (6,000 ft.), no significant seasonal movement occurs between seasonal ranges (Yost 2005b). There is no interchange with other bighorn herds because expanses of unsuitable habitat separate this herd from other herds.

Disease is not a major concern for the Carrizo sheep (Yost 2005b) since there are no domestic sheep on or near the area occupied by the herd. While there is no specific disease monitoring program within the unit, fecal samples have been collected on several occasions and have revealed no evidence of lungworm (Yost 2005b). There is, however, potential competition and definite interaction with cattle and horses throughout the herd's range.

Habitat quality is considered fair. Steep canyon walls and rocky outcroppings provide adequate escape cover. Forage quantity and quality are sufficient but could be improved with the use of fire (Yost 2005b). As with the Purgatoire Herd, tamarisk and conifer encroachment threatens much of the area, but this could be remedied through mechanical means or fire. Up to 35 bighorns are known to use dry-land rye fields frequently in Cottonwood Canyon and West Carrizo. Due to the remoteness of the area, human recreation and development are not considered concerns at this time (Yost 2005b).

4) The **Mt. Maestas Herd (Unit S64)** was started in the early 1980's when a bighorn ram (believed to be from the Greenhorn Mountain herd) was spotted chasing cattle in a rancher's field in the Mt. Maestas area. Two ewes from the Rampart Range herd were released to capture his interest. From 1983-1990, 18 additional bighorns from various sources were released in the area. Since then, the population increased to over 200 animals by 1994, then decreased dramatically when a *Pasteurella* related die-off occurred. The herd is currently estimated at 100 to 125 individuals (Vitt 2005f).

Sheep in the Plum Spring area were observed coughing in 1994, and numerous (26) dead sheep were found during a flight and ground searches in 1995 (Vitt 2005f). A baiting program, using apple pulp laced with Fenbendazole, was started at that time and has continued on an annual basis. Baiting operations have been continued past the initial die-off to address the problem of trans-placental migration of lungworm larvae to the fetus. Animals have been trapped and relocated twice after the die-off, with reported die-offs occurring in the transplanted areas after release (Vitt 2005f). Hobby flocks of domestic sheep are located within the winter range of this population, and there is one known domestic goat herd two miles from bighorn winter range within the Black Hills. Because of persistent threat of disease transmission from domestic sheep and goats, disease will continue to be a major management concern for the Mt. Maestas Herd.

During summer, sheep inhabit the slopes of Silver Mountain and Mt. Maestas, and move to lower elevations where winter range is located along the numerous volcanic dikes from east of Silver Mountain to the Black Hills east of Yellowstone Road in Huerfano County (Vitt 2005f). It is unknown if sheep historically inhabited the Mt. Maestas area. It is possible that interchange occurs with the Greenhorn population, but the intervening habitat is not very conducive to movements between the two herds. However, there are corridors with a lower tree density and scattered escape cover that would facilitate long distance movements down the east side of Greenhorn Mountain (Vitt 2005f). It is more likely that there is interchange with the Huerfano Herd since less than 10 air miles of open prairie with pinyon/juniper breaks and canyons separate the winter ranges of these two herds (Vitt 2005f).

Decades of fire suppression have detrimentally affected bighorn habitat quality within the unit. Conifers are encroaching upon lower elevation habitat, especially on the winter range. In addition, a parcel of BLM land utilized as a lambing area is slowly declining in quality. Plans are being developed to improve these habitats using prescribed burns (Vitt 2005f). Because the herd is found on private lands or public lands that are landlocked within private holdings, human recreational activities are not a major threat to the herd. However, development on some private lands in the area threatens sheep, especially by the presence of an increased number of free-roaming domestic dogs.

5) The **Pueblo Reservoir Herd** (no herd unit designation) is a small herd (always less than 30) that resulted from a translocation of 20 sheep from the Tarryall Range to the Hardscrabble Creek area in 1988 (Vitt 2005g). The herd has not prospered and is now estimated at only 12 to 18 individuals. Currently, sheep are distributed from the Pueblo Reservoir State Wildlife Area west to the Portland cement plant near Florence, primarily on the south side of the Arkansas River (Vitt 2005g). There is possible exchange with the Grape Creek Herd located 10 miles to the west.

Although habitat quality within the herd's range is good to excellent, the population is comprised of older age classes, as lamb recruitment has been chronically low. Only one lamb has been recruited into the population during the past 2 years. The magnitude of the threat of disease to this herd is unknown, but contact with domestic sheep and goats is possible (Vitt 2005g). There are few recreational impacts to this herd because it is located mostly on private land and in areas away from Pueblo Reservoir, which gets the most recreational utilization. Year-round use areas are located within a proposed subdivision, but the development schedule is unknown. If constructed, the subdivision could force sheep out of traditional use areas (Vitt 2005g).

6) The **Lower Lake Fork/Sapinero Mesa Herd** (no herd unit designation) is a small population that was initiated with two translocations in 1970 (Pike's Peak source stock) and 1975 (Trickle Mountain source stock). Twenty-two sheep were released in the Sapinero Mesa area adjacent to the lower Lake Fork of the Gunnison River canyon (Diamond 2005b). Although large expanses of habitat exist in the lower Lake Fork drainage from Gateview to Blue Mesa Reservoir, this herd has remained stagnant since reintroduction. A herd of 20 sheep was observed in the lower Lake Fork During into the early 1990's, but group sizes that large have not been seen since. The herd is currently estimated at less than 10 individuals (Diamond 2005b). Young sheep have been observed in the unit, but herd size indicates mortality is offsetting recruitment. It is likely that this small population is hindered by a variety of factors including disease, drought, habitat capability, and/or predation (Diamond 2005b).

7) The **Mesa Verde Herd** (no herd unit designation) was created by a single translocation of Rocky Mountain bighorns in the 1970's, but it has struggled since then (Wait 2005a). Some sheep are still present and use the area where Mesa Verde National Park abuts the Ute Mountain Reservation. Cliff habitat is present, but this was extensively forested until recent wildfires in 1999. Habitat conditions were improved subsequent to these fires, but there are no plans to augment the population (Wait 2005a). Wait (2005a) suggested that this area might be more suitable to desert bighorn sheep than Rocky Mountain bighorns.

Wyoming

Both Rocky Mountain and Audubon's subspecies, if substantiated by DNA technology, were historically found in Wyoming. Only Rocky Mountain bighorns are present today, estimated at approximately 6,000 individuals statewide (Hurley personal communication 2006). Eight core native herds, representing over 90 percent of Wyoming's wild sheep, occur in the Absaroka, Teton, Gros Ventre, and Wind River mountains (Hurley personal communication 2005). Bighorns are found in nearly all national forests in Wyoming, and within Yellowstone National Park. The Wyoming Game and Fish Department (WGFD) divided the state into 16 herd units, which are further divided into 19 Hunt Areas for management purposes (**Appendix B**). These herd units do not necessarily reflect biologically discrete sheep herds, but are artifacts of the management scheme. Because of the organization of this management scheme, information regarding bighorn sheep within Wyoming was primarily available in the herd unit format or hunt area format, and is treated in a similar manner in the following discussion. Bighorn sheep provide an important resource for hunters within Wyoming, and unless otherwise specified, herd units have limited hunting permits generally for rams only. Most of the following population estimates and trend data were taken from WGFD Job Completion Reports produced in 2003. WGFD personnel derived population and trend estimates using the POPII modeling program.

Shoshone National Forest: 5 herds

The Shoshone National Forest has the largest number of bighorn sheep of any forest in the system, with some 4,000 of the estimated 6,000 sheep statewide occurring on the forest (Hurley personal communication 2006). Herd Units 1-5 are not isolated from one another, and natural interchange between adjacent units is thought to be greater than 10 percent (McWhirter personal communication 2006). If interchange falls below the 10 percent threshold, WGFD considers the relevant herd units to be isolated from one another and functioning as discrete biological herds. WGFD recognizes the importance of maintaining connectivity between these herd units so that they continue to function as an effective metapopulation. Herd Units 1-4 all border Yellowstone National Park.

1) The **Clark's Fork Herd (Hunt Area 1)** is currently estimated at 425 individuals, somewhat below the management objective of 500. However, the herd is healthy, and growth is stable to slightly increasing. This is an interstate population, with portions of the herd unit sharing seasonal ranges in Wyoming and Montana, including Yellowstone National Park. However, the majority of sheep reside in Wyoming in the Absaroka Range west of the Clark's Fork River, while the Beartooth Plateau in Montana contributes 15 percent to 20 percent of the range (McWhirter 2004a). In 1995, the northern portion of the herd suffered significant mortality due to a severe spring snowstorm. There have been no significant die-offs related to disease even though domestic sheep have been grazed on allotments within or adjacent to this herd unit for several decades. However, due to the risk posed by domestic sheep, a permittee was moved to the Bighorn National Forest in 2002, eliminating a major concern for herd welfare. Movements between seasonal ranges are not currently impaired, but highway development in the Rock Creek Drainage in Montana and near the state line could become a problem if traffic volumes increase in the future (McWhirter personal communication 2006).

2) The **Trout Peak Herd (Hunt Area 2)** is currently stable at an estimated 435 individuals, 42 percent below the population objective of 750. No large die-offs due to disease or other factors have occurred. Until recently, this herd unit has not been consistently surveyed for population estimates, mainly due to budget constraints, the steep, rugged nature of the terrain, and other priorities. WGFD recognizes the need to implement a more systematic and consistent survey protocol for this herd. To this end, WGFD carried out a comprehensive aerial classification and trend count survey in April 2003, and another classification survey in April 2004. Continuation of this effort is planned on at least a bi-annual basis, which should produce more consistent and accurate data for population monitoring. During the past five years, prescribed burns have been carried out and will continue to be implemented to remove conifers that have encroached into wintering habitat (McWhirter 2004b). A total of 2,000 acres will eventually be treated. Movement of sheep between seasonal habitats is not impaired, and as part of the Northfork Highway Reconstruction, a 640-acre easement was purchased on the lower North Fork Shoshone River in 2004 that will secure habitat for bighorn sheep (McWhirter 2004b). The likelihood of encounters with domestic sheep is unknown.

3) The **Wapiti Ridge Herd (Hunt Area 3)** is the third largest bighorn herd in the state, estimated at 1,040 individuals. The size of this herd is at the management objective, and population growth is static. This herd is considered very healthy, and the hunt unit has a reputation among bighorn sheep hunters as an excellent area. Although scabies, mange, and soremouth have been documented in the population, there have been no large die-offs from any cause in the past 20 to 30 years. Habitat improvement projects on winter range in both the South Fork and North Fork Shoshone River drainages have alleviated some of the concerns expressed for this herd in the past (McWhirter 2003c). A 6,900-acre wildfire in the Blackwater Creek drainage in 2003 should also improve some sheep ranges by increasing visibility and providing increased forage.

4) The **Younts Peak Herd (Hunt Area 4)**, currently estimated at 909 individuals, is at the management objective of 900 individuals. No major barriers exist to movement between seasonal ranges. The majority of sheep winter at elevations above 9,500 ft. inside the Washakie and Teton wilderness areas. Consequently, limited opportunity exists to improve sheep habitats, with the lone exception of low elevation

winter ranges located along the upper South Fork of the Shoshone River between Deer Creek and Cabin Creek (McWhirter 2004d). The Shoshone National Forest has conducted several small, prescribed burns in the past few years, and a wildfire burned 80 acres near the Cabin Creek trailhead in May 2000. A primary habitat concern is invasive weeds; over 2,400 acres of the upper South Fork winter ranges in both Hunt Areas 3 and 4 are infested with Dalmatian toadflax (*Linaria dalmatica*), a noxious weed. Mechanical, chemical, and biological control methods have been implemented to control this invasive species. A new chemical herbicide (Plateau) appears to be effective in controlling Dalmatian toadflax, and Shoshone National Forest has increased its control efforts using this herbicide, even within designated wilderness areas (McWhirter 2004d).

5) The **Francs Peak Herd unit** includes WGFD Hunt Areas 5 (Francs Peak) and 22 (Dubois Badlands), as well as the Owl Creek Mountains in the northern portion of the Wind River Indian Reservation (WRIR). This is the largest herd in the state, currently estimated at 1,404 individuals, slightly above the management target of 1,360. Densities vary across the herd unit. In Hunt Area 5, much of the occupied habitat occurs in alpine areas of the Wood River, Greybull River, and Wiggins Fork drainages, as well as Carter Mountain (Kroger 2004). In Hunt Area 22, a number of sheep occupy the badlands north of the Wind River, as well as Black and Dennison mountains, with some sheep spending considerable time on irrigated meadows on the Fish Ranch. In the Owl Creek Mountains on the north end of the WRIR, at least 200 bighorns are found year round above 9,500 ft., with many wintering above 11,000 ft. Movement between seasonal habitats is not impaired.

In general, habitat conditions in the Francs Peak herd unit are thought to be good to very good. Although opportunities do exist for prescribed burning on bighorn sheep habitat on the Wood River, Francs Fork, and the Owl Creek Mountains, the majority of the herd unit is designated wilderness, thus limiting habitat improvement opportunities (Kroger 2004). Initial evaluations and planning for prescribed burning outside the wilderness have recently been conducted.

Limited livestock grazing occurs throughout much of this herd's occupied habitat. The Shoshone National Forest has converted several domestic sheep allotments to cattle allotments over the past several years, and this has significantly reduced the potential for transmission of diseases and improved forage availability for bighorns.

Opportunity exists to repopulate historic bighorn sheep habitat in the upper reaches of the North Fork Owl Creek drainage, which would aid in expansion of the Francs Peak Herd and increase recreational opportunities. Because of the high quality habitat available, the chances of a successful transplant are good. Although a proposal to relocate sheep to the North Fork Owl Creek was floated in the mid 1990's, the WGFD voluntarily stayed the implementation of the project due to an appeal by an oil company and concerns from several landowners (Kroger 2004). However, WGFD plans to continue working toward a transplant of sheep into the North Fork of Owl Creek. Cooperation between WGFD and the Shoshone National Forest, BLM, and private landowners in the project area will be essential.

Caribou-Targhee National Forest: 1 herd [Adjacent herd in USFS Region 4]

The **Targhee Herd unit (Hunt Area 6)** is the fifth and final unit that borders Yellowstone National Park. While growth is currently stable in this herd unit, the estimated 100 sheep is 20 percent below the management objective of 125. The overall distribution of sheep in this unit is restricted to the Teton Range in western Teton County. Currently occupied habitat is along the crest of the Teton Range and some canyons in Grand Teton National Park, with some seasonal movements onto Targhee National Forest (Brimeyer 2004a). Bighorns historically used lower elevation spring and winter ranges in Teton, Darby, Fox, and Phillips canyons, as well as the Bitch Creek drainage. However, the current confinement of bighorns to high elevation ranges is a concern for WGFD biologists (Brimeyer personal communication 2005). Movements between preferred seasonal habitats have been impaired or eliminated due to many factors, including housing development, past domestic livestock grazing, plant succession, hunting, and predation.

Conflicts with domestic sheep have historically been a problem for the Targhee Herd. In 2001, the herd suffered a 40 percent die-off, potentially due to contact with domestic sheep. Fortunately, many domestic sheep allotments have been closed within the past five years. Beginning in 2004, there were no more active domestic sheep allotments north of Highway 22 in the Teton Range. It is hoped that the retirement of these allotments will sharply reduce or eliminate the threat of disease transmission (Brimeyer personal communication 2005).

Another major concern for this herd is its relative isolation from other bighorn herds. The Targhee Herd is below the 10 percent level of exchange and functions as a discrete herd rather than as an integral part of a larger regional population or metapopulation. The best opportunity for gene flow between herds occurs on low elevation range at the southern end of the Tetons, where sheep from the Targhee and Jackson herds have intermingled on three documented occasions (Brimeyer personal communication 2005).

The most recent recommendations from WGFD include initiating a prescribed fire program to improve winter habitat conditions by reducing conifer encroachment in historic sheep habitat. In addition, because all domestic sheep allotments have been eliminated, bighorn translocations may be considered to repopulate historic winter ranges on the Targhee National Forest. It will be essential to enforce winter recreation regulations in these areas if translocations or natural repopulation is to be successful (Brimeyer 2004a).

Bridger-Teton and Shoshone National Forest: 4 herds

1) The **Whiskey Mountain Herd (consisting of Hunt Areas 8, 9, 10, and 23)**, similar to the Jackson Herd, has undergone a large population decrease and remains in decline. Accurate population estimates have been problematic due to poor population model performance (Anderson 2004), but a conservative estimate puts the population at 650 animals, well below a pre-disease high of 1,700 (in 1990) and management objective of 1,350. Population modeling has accurately tracked the overall population trend, and whatever the true population size, it is believed to be the lowest in over 20 years. Reasons for this decline are two-fold: 1) the population crashed following a pneumonia outbreak during 1990-91, and 2) average lamb recruitment declined precipitously during subsequent years and has remained low ever since (Anderson 2004). Pre-disease lamb recruitment averaged greater than 30 lambs per 100 ewes, but has averaged only 21 per 100 during 1994-2003, with a low of 10 per 100 in 2002 (Anderson 2004). Studies have been initiated to determine the potential cause of low lamb recruitment, but none has provided a conclusive explanation (Mioncyzinski 2003). Adult ewes are reproducing normally, but lamb: ewe ratios are much higher during early summer when compared to those observed in December. This suggests that lamb mortality is very high in the interim, and is the likely barrier to recruitment. Circumstantial evidence points to late July as the critical time period, and it has been hypothesized that lambs lacked several trace minerals in their diet (Anderson 2004).

Mioncyzinski (2003) examined relative trace mineral deficiencies in lambs on summer range, but the results were somewhat inconclusive; trace mineral deficiency may be a periodic problem, but it did not appear to be a chronic issue. Efforts to reduce a potential deficiency included providing mineral blocks on summer range, but several years of mineral supplementation have not remedied the problem (Anderson 2004). A 3-year predator control program, consisting primarily of coyote gunning and trapping, was initiated in 2003. Although not an experimental study, this effort may reduce predation pressure on lambs. This bighorn population will continue to decline if lamb recruitment remains low.

While the Whiskey Mountain unit has historically contained a large number of sheep, the level of individual interchange with other herd units is low, very likely less than 10 percent (Anderson personal communication 2006). The Highway 26 corridor, which is the dividing line between the Whisky Mountain Herd and units to the north, consists of fairly unsuitable sheep habitat, which limits interchange. Some exchange may occur between sheep from Hunt Areas 9 and 22, as sheep from the two units are known to co-mingle, but any interchange is probably limited (Anderson personal communication 2006). Because of the low incidence of herd unit interchange, the Whiskey Mountain Herd functions more as a discrete population rather than an integral part of a larger metapopulation.

Movements between seasonal habitats within the herd unit are not greatly impaired. However, the lack of widespread suitable escape cover has tended to concentrate sheep on limited winter ranges, leading to over-utilization of forage in these areas, especially during drought years (Anderson personal communication 2006). Habitat improvement projects such as prescribed burns have been conducted over the past few years to help alleviate this problem.

The current risk of disease transmission from domestic sheep is thought to be minimal. Most of the currently occupied bighorn range in this unit consists of designated Wilderness, where domestic sheep grazing is not permitted. There is an active domestic sheep allotment on the east side of Hunt Area 23, but the probability of co-mingling with bighorns is low (Anderson personal communication 2006). The risk from hobby flocks is also small, as their number is small and there are few areas where bighorns and domestic sheep could be sympatric (Anderson personal communication 2006).

2) The **Darby Mountain Herd (Hunt Area 24)** is an introduced population, currently stable at 55 individuals, but 70 percent below the management objective of 150. The native population was extirpated in the early 1960's due to competition with domestic sheep and illegal harvest. Intrastate translocations from the Whiskey Basin (near Dubois) to Fish Creek Mountain occurred in 1981 and 1987, using 35 and 25 sheep, respectively (Fralick 2004). Domestic sheep were removed from allotments on Fish Creek and Darby Mountain prior to reintroduction. Since being established, this herd has generally remained smaller than 100 individuals (Fralick personal communication 2005), with an estimated maximum of 150 in 1994. During 1994-1997, this herd experienced a slow but steady decline (Fralick 2004), with a probable die-off occurring sometime during the period; trend counts in 1997 and 1998 revealed approximately 40 sheep each year. The most likely cause of this decline was a disease outbreak resulting from transmission from domestic sheep. Other contributing factors may have included natural winter mortality and poor winter forage conditions.

A primary concern in this herd unit is the continued contact between domestic and bighorn sheep on summer ranges (Fralick 2004). Bighorns have been observed on active domestic sheep allotments, and domestic sheep have trespassed onto closed allotments over the past several years. Other concerns include the lack of suitable escape cover on low elevation winter ranges (Fralick personal communication 2005).

Unlike most other bighorn herds in the western part of the state, Darby Mountain is almost completely isolated from other bighorn herds. There could be genetic/individual interchange with the Jackson Herd to the north, but if so, it is likely at a very low level and has not been conclusively documented (Fralick personal communication 2005). Because the Darby Mountain Herd is small and isolated, has a history of disease-related die-offs, and continues to face the threat of disease transmission from domestic sheep, it is very vulnerable to precipitous disease-related population declines and/or extirpation. This herd has not been hunted for nine years due to an insufficient number of legal rams.

3) The **Temple Peak Herd (Hunt Area 11)** is an indigenous population of the Bridger-Teton and Shoshone national forests estimated at 30 to 40 individuals. Little is known about the herd due to allocation of personnel and management resources to other herds of greater priority (Harter personal communication 2006). The distribution of bighorns within the unit is scattered, with known wintering areas in the North Fork of the Popo Agie River, Sinks Canyon, and the Little Popo Agie River. There is thought to be little, if any, interchange with bighorns in the Whiskey Mountain or Wind River Indian Reservation populations. In 1992, the herd suffered a pneumonia die-off, and has experienced low lamb recruitment ever since. Even prior to the die-off, the herd was not thought to be very productive. Because there are no plans to retire active domestic sheep allotments within the herd unit, the herd will continue to face the threat of disease transmission from domestic sheep (Harter personal communication 2006). Consequently, there are currently no plans for translocations into the Temple Peak Herd, nor any specific management efforts planned for this herd, other than opportunistic monitoring (Harter personal communication 2006).

4) The **Jackson Herd (Hunt Area 7)** is one of the few herds whose population trend is decreasing. There are an estimated 318 sheep in the herd, 36 percent below the management target of 500. As late as 2001, the Jackson Herd was well above 500 animals and was therefore identified as a source for translocation stock. Because of the decline, testing for presence or absence of certain disease agents and parasites was undertaken, funded by grants from the Wyoming Chapter of the Foundation for North American Wild Sheep (FNAWS). Tests revealed the presence of numerous pathogens (*Pasteurella trehalosi*, *Mannheimia haemolytica*, *Arcanobacterium pyogenes*, and *Streptococcus* spp.) as well as external (*Psoroptes* spp. ear mites) and internal (*Eimeria* spp. and *Protostrongylus* spp. lungworm larvae) parasites (Brimeyer 2004b). Testing continued through early 2003, over which time WGFD documented 130 mortalities. Due to this disease outbreak (a specific causative agent was not identified), field observations on low elevation winter range (Gros Ventre, Flat Creek, Curtis Canyon, and Miller Butte areas) revealed 40 percent mortality across the herd unit, and mortality as high as 60 percent in some localized wintering areas (Brimeyer 2004b). The southeastern corner of this herd unit still has an active domestic sheep allotment that will remain a disease threat into the future, a concern for the ongoing management of the herd (Brimeyer personal communication 2005). This herd is no longer considered a source for translocation animals.

The Jackson Herd is not as isolated from other herds as the Targhee, with more opportunity for gene flow with herds to the north. Seasonal movements are not greatly impaired. There is good opportunity for down-drainage movement, allowing utilization of higher quality low-elevation wintering sites, but there is also potential competition with elk on these sites (Brimeyer personal communication 2005).

Bighorn National Forest: 1 herd

In 1973, 39 sheep from the Whiskey Mountain Herd were translocated to BLM-administered lands in the **Devil's Canyon Herd unit (Hunt Area 12)**, where they joined bighorns within the Bighorn Canyon Recreation Area in Montana. This remnant population persisted and was estimated at about 50 individuals in 2003. In 2004, 20 bighorns from the Deschutes River in Oregon were translocated to BLM land within the herd unit. This source population was chosen because of its propensity for earlier lambing, a characteristic that was believed to provide an advantage in the environmental conditions found in the Devil's Canyon Herd Unit (Easterly personal communication 2006). In 2006, an additional 20 bighorns from the Missouri River Breaks near Havre, Montana were translocated to the same area as the 2004 release, bringing the total estimated herd size to 110. These sheep were also known to show a propensity for early lambing and were chosen as a source population largely for that reason. Personnel from WGFD expect that the present herd will likely increase and potentially become a source for future translocations (Easterly personal communication 2006).

These sheep were translocated to BLM land rather than the nearby Bighorn National Forest because of the active domestic sheep allotments found on the forest (Easterly personal communication 2006). There are no plans to vacate these allotments, which are utilized by the permittee that was moved from the Shoshone National Forest to the Bighorn in order to protect a core, native bighorn heard in the Beartooth Range (Hurley personal communication 2006). It is possible that a few bighorn sheep, especially rams, from the remnant population in the Bighorn Canyon Recreation Area have occasionally used areas on the Bighorn National Forest in past years, and there is an ongoing investigation of the movements of these sheep via a radio-telemetry study (Hurley personal communication 2006).

Based on the first two years of observation following the initial translocation, it appears as if the newly introduced herd does not undertake large seasonal movements, which was characteristic of their original source populations (Easterly personal communication 2006). Therefore, habitat improvement projects are in the planning stages for selected areas currently in use, including prescribed burns to reduce decadent sagebrush stands and juniper encroachment and development of water sources.

This herd is isolated from other bighorn herds within Wyoming; therefore, no natural interchange should be expected, and it will not naturally function as part of a larger metapopulation within the state. If, however, the population grows as expected, it could become a source for translocations.

Medicine Bow National Forest: 3 herds

All bighorn sheep on the Medicine Bow National Forest have been reintroduced, and are currently designated a species of local concern on the Medicine Bow National Forest.

1) The **Douglas Creek Herd (Hunt Area 18)** occupies the Snowy Range, where native bighorn populations were extirpated around 1900 (Guenzel 2004a). The translocation history within the herd unit has included four separate attempts: an unsuccessful attempt in 1929, a successful translocation of 28 and 13 sheep to two separate areas in 1970, and augmentations of six and 16 sheep in 1989 and 1990, respectively. Following the initial successful reintroduction, the herd increased rapidly over the next seven years to 200 individuals, but it has steadily declined ever since. The herd, currently estimated at about 100 individuals, is stagnant or decreasing, and is far below the management objective of 350 (Guenzel 2004a).

Several factors have contributed to the poor performance of this herd. Foremost among these was the reintroduction of bighorn sheep onto low-elevation winter range. Consequently, these animals did not develop a strong propensity for seasonal migration to higher elevation summer ranges containing lush forage. In addition, conifer encroachment into formerly suitable open habitat has effectively eliminated potential migration routes between winter and summer ranges, and restricted escape cover to isolated patches. Competition for forage with elk and mule deer on winter ranges, and with cattle on certain high quality lambing ranges, has also been detrimental to this herd (Guenzel 2004a).

The other primary limiting factor for this herd has been the nearly constant threat of disease transmission from domestic sheep. Although sheep grazing allotments in the Snowy Range have been vacant since 1997, livestock operators could apply for permits to graze them at any time. Several hobby flocks also occur within or adjacent to the herd unit (Guenzel 2004a). Because of this persistent threat, the Douglas Creek Herd is quite vulnerable to dramatic declines or extirpation, and it is currently designated as a low priority herd (Priority 3, the lowest) within the Medicine Bow management scheme. The herd is also quite isolated from bighorns in adjacent herd units, one of which (Encampment River) has a very bleak outlook.

2) The **Encampment River Herd (Hunt Area 21)** occupies the Encampment River Canyon west to the Continental Divide, in the Sierra Madre Range. It is one of the most imperiled bighorn populations in Wyoming. Established in 1977 with a translocation of 68 bighorns, the founder population initially exhibited good reproductive performance and increased to about 130 animals over the next five years. However, a severe winter during 1983-84 inflicted significant mortality from which the herd has never recovered. The stagnant to decreasing population is currently estimated at about 50 individuals, 75 percent below the management objective of 200. Several factors have been linked to the poor performance of this herd, including the widespread presence of domestic sheep, low lamb recruitment, drought, long-term fire suppression, lack of strong seasonal migration tendencies, incompatible land uses, and poor habitat quality (Guenzel 2004b).

Efforts aimed at improving conditions for bighorns within the herd unit have been implemented. These have included clearcutting and fertilization of dense timber stands, let-burn wildfire policies and prescribed burns, installation of guzzlers, and road closures. Unfortunately, none has had a significant positive impact on the population (Guenzel 2004b). Due to the myriad of issues facing the Encampment River bighorns, the recent revision of the Medicine Bow National Forest Plan prioritized domestic sheep grazing over bighorn conservation in the Sierra Madres. Several active domestic sheep grazing allotments are located throughout the herd unit, and the Encampment River bighorns face an extreme risk of disease transmission and associated mortality. WGFD has acknowledged that the Encampment River Herd is likely to be extirpated again (Guenzel 2004b). Although the herd unit has not been hunted since 1987, the recent change in priorities prompted WGFD to reopen a hunting season in 2004 to take advantage of the recreational opportunity to harvest mature rams that would otherwise die of other causes under the current management scheme. The Encampment River Herd will continue to provide recreational viewing opportunities and limited hunting in the short term, but it should not be expected to persist nor contribute to the long-term conservation of bighorn sheep on the Medicine Bow National Forest.

3) The **Laramie Peak Herd (Hunt Area 19)** is the largest bighorn herd on the Medicine Bow. It currently is estimated at 250 to 300 individuals and is increasing, but it remains well below the objective of 500. This herd occupies the Laramie Range, where bighorns were considered abundant before settlement. Following the original reintroduction of 40 sheep in 1964, the subsequent translocation record is extensive: five separate translocations involving 146 sheep reintroduced into three locations between 1965 and 1989.

Of the three herd units within the Medicine Bow, the Laramie Peak Herd unit appears to have the best long-term outlook. Within the past five years, fairly large (over 39,000 total acres in 2002 alone) wildfires have had a positive effect on important bighorn habitat throughout the herd unit. It is expected that these fires will reduce conifer encroachment, set back less desirable late seral vegetation stands, open up much needed travel corridors to connect sub-herds within the herd unit, and increase the quality of lambing and nursery areas (Hicks 2004).

Although two sheep have been documented with pneumonia in recent years, no major disease-related die-offs have occurred (Hicks 2004). There are no major groups of domestic sheep within occupied bighorn range, but small hobby flocks occur in the North Laramie Drainage and will continue to pose a disease threat. Other factors that could limit the success of this population include isolation from other bighorn populations, with limited opportunity for movement between sub-herds. Approximately 90 percent of the herd unit is composed of private land, and potential conflict between local landowners and bighorn sheep hunters may complicate management efforts in this herd unit.

Other herds in Wyoming not located on National Forest System lands: 3 herds

1) The **Seminoe-Ferris Herd (Hunt Area 17)** was initiated in the 1940's with two small translocations into the Ferris Mountains. One of these translocations was of desert bighorns from Nevada (Hiatt 2004). Other slightly larger translocations were made in the 1950's and 1960's, without the herd obviously becoming self-sustaining. In 1978 and 1980, 100 bighorns were translocated to the Seminoe Mountains, after which

a self-sustaining population appeared to establish. Although the growth rate of the herd was low, young sheep were being recruited into the population (Hiatt 2004). However, after 1980, several factors acted to bring about the steady decline. Currently, this herd is best described as a remnant herd comprised of only about 15 individuals divided between the Ferris and Seminoe mountains. Three years of intensive monitoring identified poor forage quality during summer as the primary factor in low lamb survival and recruitment (Hiatt 1997). Illegal harvest and other non-consumptive mortality have exacerbated the problem (Hiatt 2004). There are currently no active domestic sheep allotments within the herd unit.

Habitat improvement projects such as prescribed burns were planned in 1990 but not implemented due to weather and soil moisture concerns. When conditions were appropriate to initiate burns in the mid 1990's, it was deemed that there were too few sheep left to benefit from the project (Hiatt 2004). This herd will almost certainly be extirpated without supplementation, and forage/habitat conditions must be improved before additional translocations are considered.

2) The **Sweetwater Rocks Herd unit (Hunt Area 16)** contains only a handful of bighorns. WGFD personnel have observed six to eight sheep, with another recent unsubstantiated sighting of 35 (Harter personal communication 2006). If this report is true, these sheep were probably wanderers from the Seminoe/Ferris population. WFGD proposed a translocation to the unit approximately six to eight years ago, but conflicts with local ranchers derailed the proposal. There currently are no plans to try to increase the herd. Bighorns within this unit are relatively secure from interaction with domestic sheep, as they tend to remain relatively sedentary in a core area that is sufficiently removed from the nearest domestic flocks (Harter personal communication 2006). Still, this remains a low priority bighorn population for WFGD, with no specific management plan other than opportunistic monitoring.

3) The **Yellowstone Herd** (no Hunt Area designation) was estimated at 244 sheep in spring 2005 based on helicopter surveys. Thirty-four lambs per 100 ewes were observed, compared to an average of 22:100 (range = 7-32) during 1995-2003. Recruitment has been relatively high (21 to 34 lambs per 100 ewes) since 1999, compared to seven to 22 lambs per 100 ewes during 1995-1998, and the herd appears to be increasing.

While bighorns do not interact with domestic sheep within park boundaries, they do come into contact with domestic sheep in grazing allotments located adjacent to park boundaries. To alleviate potential conflict between domestic sheep and wildlife, including Yellowstone bighorns, the National Wildlife Federation has bought out several domestic livestock allotments surrounding the park. Negotiations are currently underway to buy out an additional domestic sheep allotment that totals 74,000 acres (National Wildlife Federation 2005). This allotment is only 3 miles from the northern park boundary and is frequented by Yellowstone bighorns. Retirement of this allotment will significantly expand the amount of conflict-free habitat available to bighorns. Thus, there is reason for guarded optimism regarding the future of this relatively small and isolated population (White 2005).

South Dakota

The Audubon's subspecies of bighorn sheep (the only subspecies known to be native to South Dakota; see discussion of subspecies in Systematics and description) was extirpated within the state by 1910. The cause is unknown but presumed to be unregulated hunting. The current statewide population, estimated at 415 individuals, consists of the Rocky Mountain subspecies, which were translocated from source populations in Colorado, Wyoming, New Mexico, and Alberta (Benzon personal communication 2005, Childers personal communication 2005). Three herds occur on the Black Hills National Forest and one in Badlands National Park. All sheep have been reintroduced into historic Audubon's habitat. Without management intervention, all herds are isolated from bighorn populations in other states.

Black Hills National Forest: 3 herds

1) The **Custer State Park Herd** is currently estimated at 50 individuals, with a management objective of 150. In 1922, eight Rocky Mountain bighorns from Alberta, Canada were translocated to Custer State Park within the Black Hills. This herd was reduced to one individual by 1959 due to unknown causes. The herd was re-established in 1965 using 22 sheep translocated from Whiskey Mountain, Wyoming, and it subsequently increased to approximately 150 individuals by 1975. Herd growth then became static, perhaps due to low lamb recruitment (South Dakota Game, Fish and Parks Department 2000), and 20 additional sheep were translocated to Bear Gulch in

1999 from Alberta, Canada to increase genetic diversity and to fill unoccupied range. In 2005, the herd again suffered a die-off (75 percent) due to pneumonia suspected to have been transmitted from domestic sheep. A new source of sheep is currently being sought to augment the herd again. Summer, winter, and lambing range conditions are thought to be fair, and wildfires within the past decade have created 2,400 acres of new ewe/lamb habitat. Impediments to the future growth and health of this herd include continued risk of disease transmission from domestic sheep and encroachment of conifers into suitable sheep habitat (Benzon personal communication 2005).

2) The **Spring Creek Herd** was established in 1991 with 26 individuals from Georgetown, Colorado, and augmented in 1992 with an additional five sheep from the Badlands Herd. The herd currently numbers 225 individuals and is in good health with increasing numbers (Benzon personal communication 2005). Active habitat management has aided the growth of this herd, and has included pre-introduction clearcutting and burning of 150 acres of dense pine stands, and post-introduction treatment of an additional 200 acres. Impediments to future growth and health of this herd include subdivision development, highway construction, and livestock grazing, but the threat of contact with domestic sheep is thought to be low. The condition of summer, winter, and lambing range is good, and the herd is not severely isolated, at least within the Black Hills ecosystem (Benzon personal communication 2005). These factors should provide continued opportunity for this herd to expand to the management objective of 300 to 400 animals and become a source for transplant stock, as well as provide limited hunting opportunities (a hunting season was initiated in 2000, with a limit of two sheep).

3) The youngest herd within the state is the **Elk Mountain Herd**, numbering 50 individuals. Established in 2001 with 20 source animals from the Spring Creek Herd, it was augmented in 2004 with seven sheep from Wheeler Peak, New Mexico. The herd is currently increasing, with a management objective of 300 to 400 individuals. The good condition of summer, winter, and lambing range should allow this herd to continue to increase. There is opportunity for genetic exchange with other herds within the Black Hills ecosystem, but a moderate risk of disease transmission from domestic sheep, continued subdivision development, livestock grazing, and highway construction may ultimately limit herd size.

Badlands National Park: 1 herd

The **Badlands National Park Herd**, initiated in 1964 using 22 animals from Pike's Peak, Colorado, currently numbers 90 individuals (Childers personal communication 2005). The original transplanted animals were placed in a 370-acre enclosure within the park in an effort to establish a self-sustaining source of sheep for future translocations within the state. However, an unknown disease reduced the captive herd to 16 individuals and remaining sheep were released into the park in 1967. Nonetheless, the herd grew and was estimated at 133 to 200 individuals in 1989-1990. However, an outbreak of epizootic hemorrhagic disease from 1995 to 1997 reduced the herd by 60 percent. An additional 24 animals were translocated from Wheeler Peak, New Mexico in 2004, and the herd is again increasing toward the management objective of 200 individuals.

While the condition of summer, winter, and lambing range of the herd is good, the herd is completely isolated. Livestock grazing, highways, and development have severed historical linkages to other herds permanently. The primary range of this herd lies within the Sage Creek Wilderness, which is devoid of roads and contains limited recreational hiking trails (South Dakota Game, Fish, and Parks Department 2000). It is believed that domestic sheep do not currently threaten this herd (Childers personal communication 2005).

The future of bighorn sheep management within South Dakota will depend on active management to the maintenance of genetic diversity herds using transplants among herds currently found in the state, and the introduction of new individuals from bloodlines outside the state. The entire statewide population will be managed as an artificial metapopulation through active intra-state and inter-state translocations.

Nebraska

Historically, the Audubon's subspecies was found in Nebraska, but it was extirpated in the early 1900's (Toweill and Geist 1999). The current statewide bighorn population, approximately 110 individuals, is comprised of introduced Rocky Mountain bighorns (Schlichtemeier personal communication 2005). Three herds have been re-established into historic Audubon's habitat from Rocky Mountain bighorn stock obtained in Montana, Colorado, and South Dakota. Two herds occur on the Nebraska National Forest and one on state-owned lands at Cedar Canyon Wildlife Management Area. All Nebraska bighorn herds are isolated from bighorn populations in other states.

Nebraska National Forest: 2 herds

1) The **Fort Robinson Herd** is the oldest within the state, having been established in 1981 with 10 animals translocated from the Custer State Park herd in South Dakota. The primary range of this herd encompasses Fort Robinson State Park, Soldier Creek Wilderness, and the Peterson Wildlife Management Area. In 2004-2005, the herd suffered a 50 percent die-off (it now numbers around 60 individuals) due to *Pasteurella* and is in continued decline (Schlichtemeier personal communication 2005). The die-off is currently ongoing, and it is expected that more sheep will be lost (Darveau personal communication 2006). There are small herds of domestic sheep near bighorn range, and the potential for disease transmission from these herds is almost certainly the cause of the recent die-off. One ram is known to have been killed due to contact with domestic sheep.

Management objectives for this herd include increasing this free-ranging population, and providing hunting and public viewing opportunities within the limit of the resource and the limit that most landowners will accept. There are no known deficiencies in summer, winter, or lambing range. Impediments to the future growth and health of this herd include risk of disease transmission from domestic sheep, the presence of electric fences that may negatively affect movements between seasonal habitats, human disturbance during the lambing season, potential competition with domestic livestock (Klinksiek 2003), and continued housing development (Schlichtemeier personal communication 2005). Research has been conducted regarding gender-related differences in diet and habitat and the possible presence of lungworm through collection of fresh fecal samples (Klinksiek 2003).

2) The newest herd in the state is the **Montana Herd**, established at the Bighorn Wildlife Management Area using 49 animals translocated from Montana in January 2005. Since that time, the herd has increased to 54 individuals and has not suffered any die-offs. Two ewes have moved to the Fort Robinson Herd, a distance of 15 miles, demonstrating the potential for exchange between the two herds (Schlichtemeier personal communication 2005). Most sheep are outfitted with radio-collars for monitoring, but seasonal ranges have yet to be clearly defined. Presently, the herd is broken up into at least two groups that are distributed nearly 20 miles from each other (Darveau personal communication 2006). As with other herds in the state, small bands of domestic sheep are present within bighorn range, creating a high risk of continued disease transmission to the bighorn herd. One ewe has been killed by state biologists due to contact with domestic sheep. There are plans to translocate an additional 50 individuals into this area.

Cedar Canyon Wildlife Management Area: 1 herd

This recently-established herd was initiated with 22 animals translocated from Colorado in March 2001. It subsequently increased to 64 individuals (Schlichtemeier personal communication 2005), but a *Pasteurella* die-off within the last year has reduced the herd by about 50 percent (Darveau personal communication 2006). The herd is isolated from other bighorn populations, and domestic sheep within the herd's range make it susceptible to disease-related die-offs. Both of these factors increase the herd's vulnerability to extirpation. A portion of the sheep are radio-collared, and current research is focused on hoof deformities, establishing seasonal foraging habitats, identifying differences in ewe and lamb diet selection, and establishing baseline trace mineral levels across habitats and within the sheep themselves. The radio-collared individuals are being monitored daily, a significant advantage in detecting additional *Pasteurella* infections and treating any outbreaks (Darveau personal communication 2006). Management and impediments to future growth and health are similar to those of the Fort Robinson and Montana herds (Schlichtemeier personal communication 2005).

Region 2 summary

Throughout the previous discussion, several conservation issues were repeatedly identified as common threats to bighorn herds throughout Region 2. Foremost among these were:

- ❖ susceptibility of bighorns to disease transmission from domestic sheep and goats,
- ❖ lack of population connectivity and genetic interchange among bighorn populations, and
- ❖ decades of continued fire suppression and/or other factors causing decline in habitat quality, leading to reduced habitat suitability for bighorn sheep.

The relative importance of the latter two threats can be debated, and their importance is variable from location to location. However, the risk of devastating disease outbreaks resulting from contact with domestic sheep and goats is firmly established and is widely believed to be the most dire threat facing regional bighorn populations. Gross et al. (2000) reported that in the absence of disease, simulated extinction rates for bighorn sheep were uniformly low, and that efforts to reduce the frequency and severity of disease epizootics should be the highest priority in attempts to restore bighorn sheep populations. Bearing these three primary threats in mind, and using the previous descriptions of individual Region 2 bighorn herds, we were able to examine the current state of bighorn sheep throughout the Region, and to identify areas that we considered to be strongholds for bighorns (low risk of extirpation), others that were in danger of extirpation or likely to show continued chronically poor production (high risk), and others that, given the requisite conditions, could go either way (medium risk). Herd unit descriptions were not available for all herds in Colorado, resulting in an incomplete picture of the status of all bighorn sheep herds in that state.

Low-risk herds

Areas included in the category of strongholds shared several characteristics. The primary characteristic was that the risk of disease outbreaks was minimal, as evidenced by a history free of disease-related die-offs, or if die-offs have occurred, the suspected cause (i.e., domestic sheep or goat herds) has been removed or significantly lessened. In addition, the individual bighorn populations in a stronghold area exhibited a naturally occurring metapopulation structure, ensuring a significant degree of genetic exchange among herds. Finally, habitat quality was not a limiting factor in terms of imposing impediments to seasonal migration or causing poor herd health due to nutritional deficiencies. Areas considered as strongholds also had relatively large populations and were potentially capable of producing excess animals that could be used for translocations. Stronghold areas are critical resources for the future of the bighorn population within Region 2.

The first obvious stronghold within Region 2 is northwestern Wyoming, specifically units 1, 2, 3, 4, and 5, where some 4,000 bighorn sheep occur on the Shoshone National Forest (**Figure 7**). These herd units are well connected, allowing movement between populations, consist of the largest populations in Region 2, have been free of disease-related die-offs, and occupy an area where the threat of domestic sheep contact has been removed or dramatically reduced (Hurley personal communication 2006). Seasonal movements are not greatly impaired, and habitat quality is not a limiting factor. As a bighorn stronghold, this area could be an important source of animals for future translocations.

A second stronghold area occurs in south-central Colorado (**Figure 8**), including herd units S8, S9, S49, S65, and S51. These five herd units contain a combined estimated population of over 1,100 individuals, with at least minimal natural exchange between adjacent populations. No active domestic sheep allotments are known to be present within or near these herd units, and disease-related die-offs have been rare or nonexistent. While declining habitat conditions in portions of this area have not seriously hindered bighorn herds, future habitat treatments in certain areas would likely help to maintain or increase herd size.

Medium-risk areas

Areas that we consider medium-risk include all those not found in the high or low-risk categories. They generally share a combination of characteristics from the high and low-risk areas. For instance, the Laramie Peak herd unit in Wyoming is a fairly large population (250 to 300) that is increasing, and has recently experienced significant habitat improvements. However, hobby flocks of domestic sheep are present in one drainage within the unit, which is isolated from other bighorn populations. Other medium-risk areas in Wyoming are scattered throughout the state, and include the Targhee, Devil's Canyon, Jackson, and Whiskey Mountain herd units. Within Colorado, medium-risk areas are also scattered and include herd units S1, S3, S4, S6, S12, S15, S16, S18, S28, S31, S32, S38, S46, S48, S50, S61, S64, and S66. Other medium-risk areas include the Spring Creek, Elk Mountain, and Badlands National Park herds in South Dakota. Because medium-risk areas face fewer total threats, or less dire threats, than high-risk areas, they are most likely to benefit from the expenditure of management resources. All things being equal, medium-risk herds would benefit more than high-risk herds if an equal amount of critical management resources were spent on each.

High-risk areas

Bighorn herds in the high-risk category share one or more primary characteristics: 1) a history or significant threat of disease-related die-offs or extirpation, and/or subsequent chronically poor production, 2) small population size, 3) total or near complete isolation from other bighorn populations, 4)

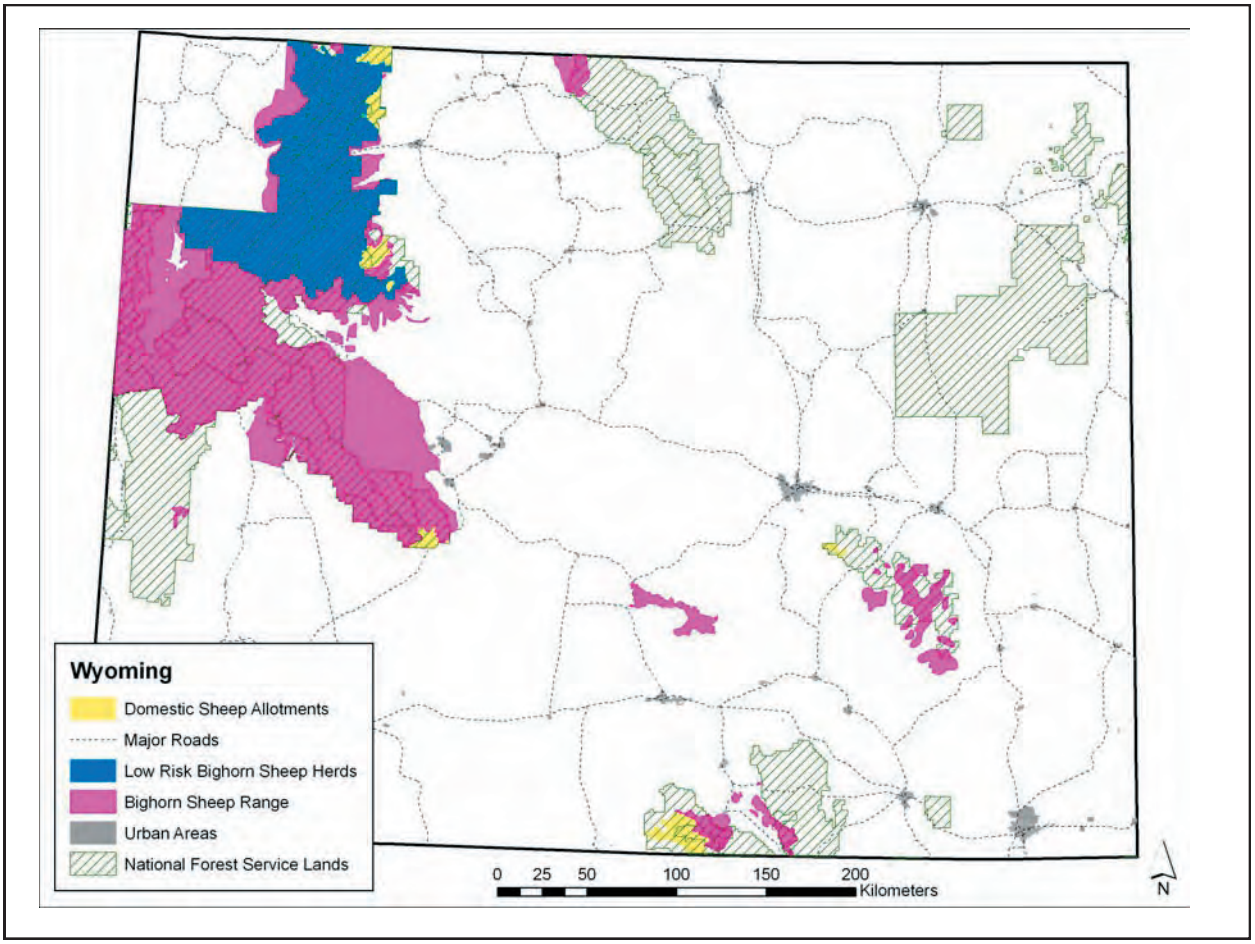

Figure 7. Bighorn sheep herds with low risk of extirpation in Wyoming.

poor habitat quality leading to poor nutrition, or (5) significant obstacles to seasonal movement.

When identifying high-risk areas, we began by examining a herd's degree of isolation from other bighorn populations. In Wyoming, herds that are significantly isolated included those in the Darby Mountain., Seminoe/Ferris, Sweetwater Rocks, Encampment River, Douglas Creek, and Temple Peak units (**Figure 9**). None of these populations exceeds 100 individuals (range 6 to 100), most have experienced significant die-offs or continue to face threats of disease transmission from domestic sheep, and there are significant habitat concerns in many units. For similar reasons, obvious high-risk areas within Colorado include herd units S10, S12, S20, S23, S27, S29, S30, S53, S55, S62, S63, S69, and the Pueblo Reservoir, Mesa Verde, and Lower Lake Fork/Sapinero herds (**Figure 10**). Additional high-risk areas include the Custer State Park population within South Dakota, and all three herds in Nebraska.

Because wildlife management is conducted in an arena of limited resources, the best overall management strategy may be a "hands off" policy for some high-risk areas, many of which face multiple threats that would drain critical management resources. Often, these resources would be better utilized by maintaining stronghold areas or addressing the lesser threats faced by herds in medium-risk areas. Obviously, such decisions are best made on a case-by-case basis at the local level.

Management of Bighorn Sheep in Region 2

Population management

Bighorn sheep management is complicated in some respects by the different authorities of the agencies responsible for managing bighorns and their habitats, and the fact that both state and federal land management agencies share trustee responsibility for wildlife. State wildlife agencies have authorities and responsibility for managing bighorn populations, including regulating the harvest of bighorns by sport hunters, and manipulating bighorn populations through the translocation of bighorns into unoccupied habitat

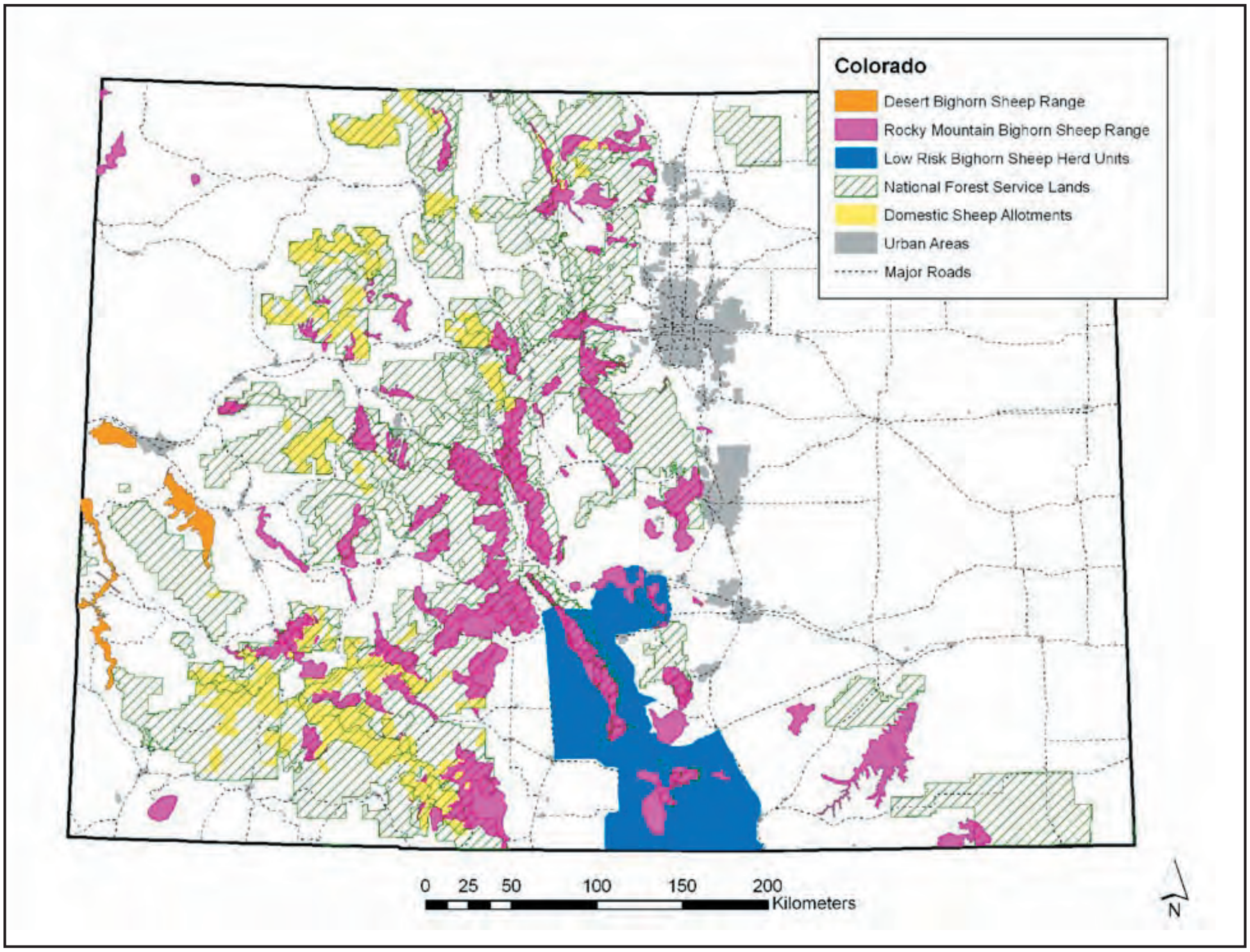

Figure 8. Bighorn sheep herds with low risk of extirpation in Colorado.

or for purposes of augmenting small populations. However, the USFS has administrative authority over National Forest System lands and the resources they contain. The National Forest Management Act requires the USFS to provide for diversity of plant and animal communities on National Forest System lands. Still, the USFS and other federal land management agencies focus much of their effort on managing habitat to provide for sustainable populations, while cooperating with state agencies in actions necessary to manage effectively for the population health of species of joint interest and responsibility. State and federal agencies seek to develop effective management programs for bighorn sheep that involve interagency coordination and cooperation on a regional landscape basis in Region 2 (Douglas and Leslie 1999).

National forests in Region 2 continue to provide domestic livestock grazing allotments, which can result in contact between domestic and bighorn sheep and lead to catastrophic disease transmission to bighorn populations. Due to the low demand for mutton and wool, many of these allotments are currently vacant and present no threat to resident bighorn herds. However, interest has been expressed in activating some of these allotments (Woolever personal communication 2005), and efforts continue by the USFS to avoid creating conflicts. Bighorn conservation groups have intervened to facilitate retiring or exchanging domestic sheep allotments in habitat occupied by bighorn sheep. Because disease may represent the most significant threat to bighorn sheep in Region 2, especially on national forests with domestic sheep grazing allotments in or near bighorn sheep habitat, the creation of effective separation between bighorns and domestic sheep and goats is likely critical for preventing disease epizootics in areas where there is potential for contact. BLM Guidelines (Bureau of Land Management 1992) suggest maintaining a minimum buffer of 13.5 km (9 miles) between domestic sheep and goats and wild sheep on BLM lands to minimize the risk of contact between the two groups. However, it is unlikely that setting hard and arbitrary guidelines for buffer zones will work effectively in all situations. In many cases,

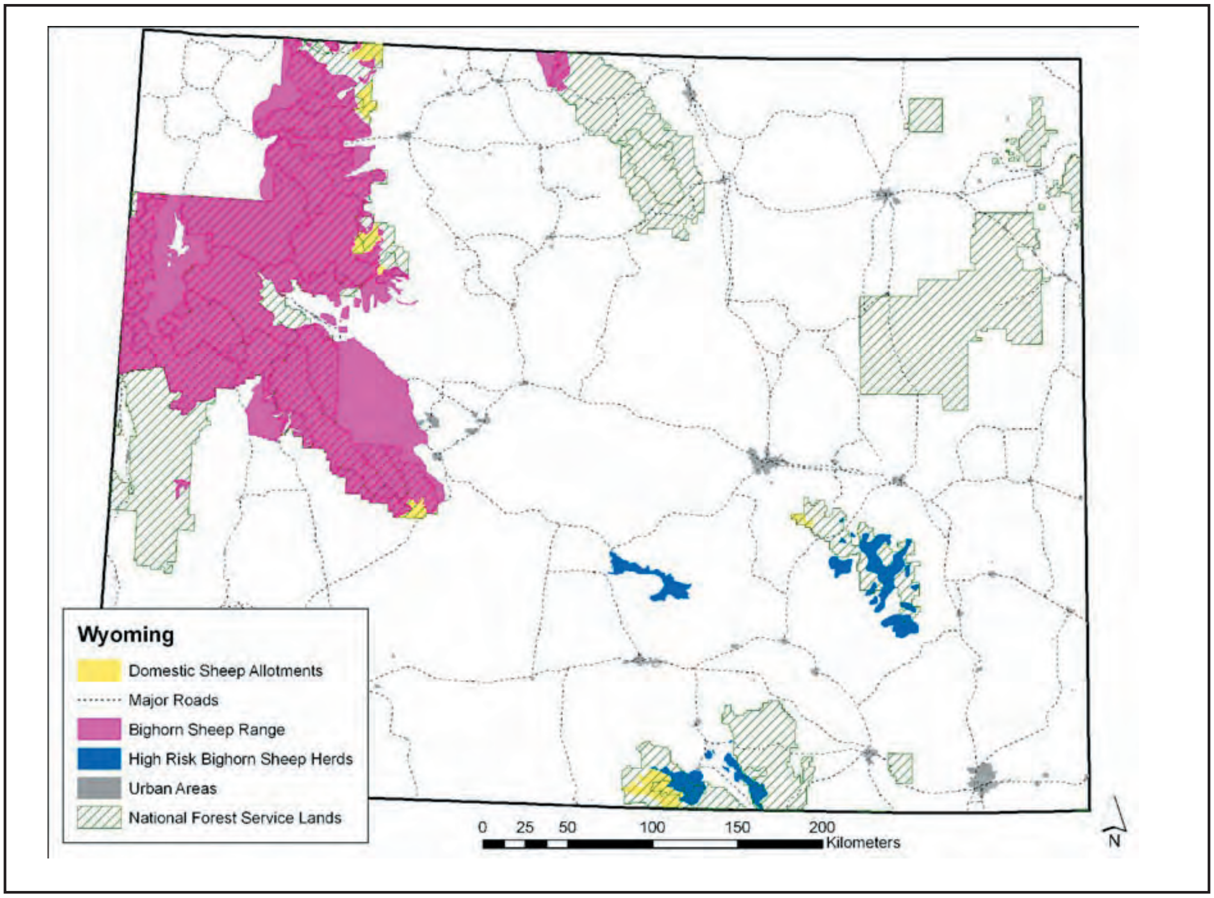

Figure 9. Bighorn sheep herds with high risk of extirpation in Wyoming.

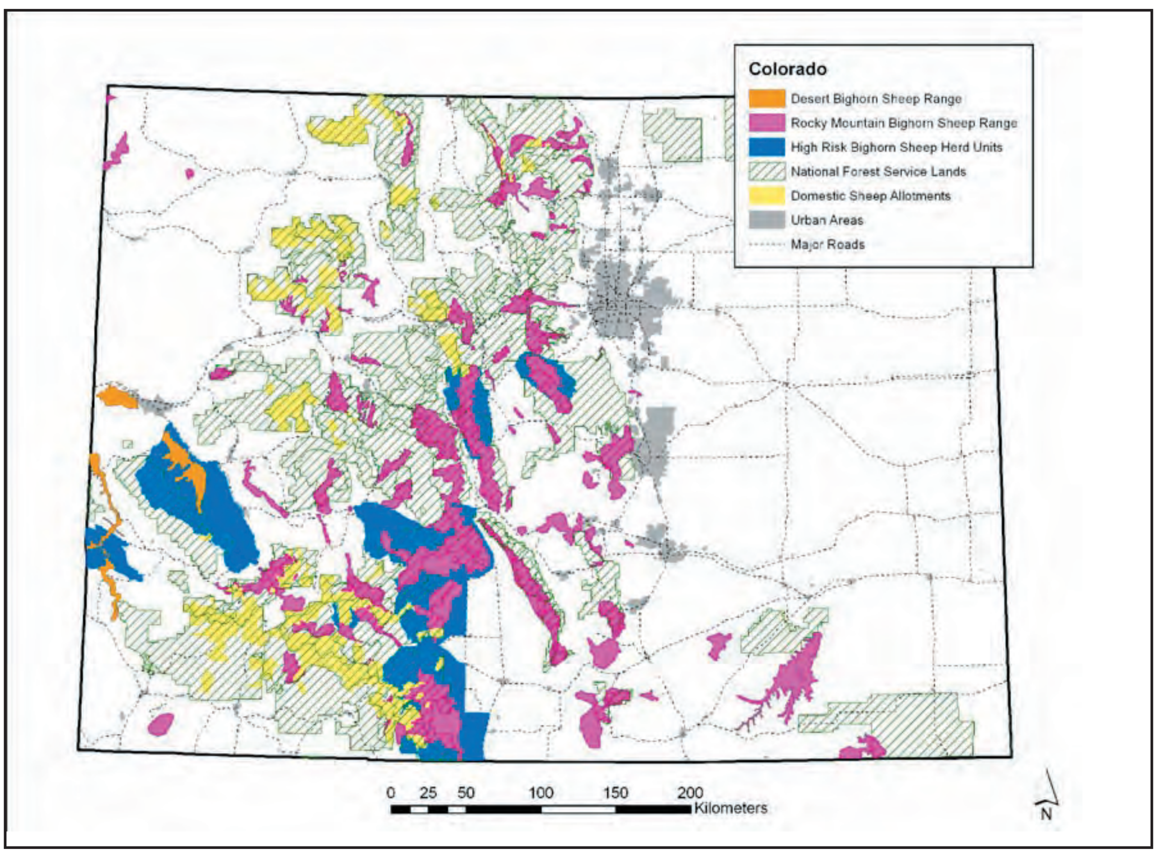

Figure 10. Bighorn sheep herds with high risk of extirpation in Colorado.

topographic features of the landscape, herd dynamics, and other variables may reduce the effectiveness of buffer zones. Buffer distances need to be flexible to reflect local conditions. The USFS FULL CURL Program suggests that it is imperative that bighorn sheep be kept separated from domestic sheep and goats (Schommer and Woolever 2001).

Bighorn sheep management strategies that focus on long-term objectives and strive for self-perpetuating populations may not require continuing intervention to maintain population stability in large (over 250 animals) herds. Schwartz et al. (1986) were among the first to suggest managing bighorn sheep on a landscape level (metapopulation) that included consideration of travel corridors between mountain ranges or herd units. Metapopulation management strategies that consider the spatial distribution and connectivity of bighorn habitats have important implications for the conservation of bighorn sheep (Wehausen 1979). As bighorn sheep habitat becomes increasingly fragmented as a result of plant succession, management activities, or human encroachment, many of the smaller bighorn populations in Region 2 may be at risk of extirpation from natural stochastic events unless landscape level management strategies are put in place to ensure gene flow among these small herds (Crow and Kimura 1970, Helvie 1971, Schwartz et al. 1986, Bleich et al. 1990b, 1996, Torres et al. 1996). Management efforts that focus on increasing the overall number and distribution of bighorn sheep, the connectivity among herds, and the size of female groups within existing herds require coordinated landscape level management actions to protect large blocks of sheep habitat from degradation, and to ensure the long-term viability of individual herds in Region 2.

Maintaining or restoring connectivity of populations in fragmented habitat requires landscape-level analyses and cooperation among state wildlife agencies, land management agencies, county and regional planners, transportation agencies, and private landowners to ensure long-term persistence of wild sheep populations in Region 2. Habitat connectivity is essential to maintaining the metapopulation structure of bighorn sheep populations, and herds occupying isolated fragments of habitat are at risk of extirpation. Consequently, identifying travel corridors connecting fragmented bighorn ranges is an important responsibility of habitat managers. Landscape scale genetic analyses can identify bighorn populations that are or were recently linked, and help quantify the need to protect migration and travel corridors (Sinclair et al. 2001, McRae 2004). Global Positioning System (GPS) radio collars can also be used to identify movement corridors at smaller scales. Habitat managers interested in the protection or restoration of travel corridors should consider a variety of factors, including habitat quality in the travel corridor, length and area of the corridor or potential corridor, public acceptance of the proposed action, and the cost to maintain, restore, and manage these corridors.

Another significant consideration in managing wild sheep on a metapopulation basis is their vulnerability to disease organisms carried by domestic livestock. Developing movement corridors among relatively discrete sheep herds has the potential to increase gene flow naturally among those herds and to provide for a natural population rescue effect through dispersal (Hogg et al. 2006), but it can also facilitate the flow of disease organisms among the herds and trigger disease epizootics (Hess 1996). Managers should evaluate the disease risks associated with efforts to increase connectivity among herds.

Intensive, ongoing management, including trapping and transplant programs, will often be necessary with smaller and isolated bighorn sheep herds. Such programs have resulted in significant increases in the number and distribution of bighorns herds decimated by disease in the past 40 years (Valdez and Krausman 1999). Active translocation projects may continue to be necessary to augment small, isolated bighorn herds periodically or to establish herds in historic, but unoccupied habitats. The recommended minimum number of animals for an initial transplant into unoccupied habitat is 20 mixed-age ewes and young rams with a sex ratio of about one male:three to five ewes (Rowland and Schmidt 1981, Wilson and Douglas 1982). Rowland and Schmidt (1981) cautioned that care should be taken to ensure that transplanted animals do not become another relict group, and that there is sufficient habitat potential to allow the population to expand to more than 100 individuals either naturally or through subsequent translocations (Berger 1990). Maintaining or re-establishing severed travel corridors linking recently transplanted sheep to other bighorn herds can mitigate the effects of genetic drift or inbreeding that can affect isolated herds with small numbers of effective breeders (Ellstrand and Elam 1993, Fitzsimmons et al. 1997, Hogg et al. 2006). Transplant sites should contain adequate escape terrain to support 60 to 70 ewes for the area to maintain an effective population size of at least 100 animals.

Despite the increases in productivity and survival that Hogg et al. (2006) observed when they experimentally restored migration in an Alberta bighorn population, augmenting herds that are using poor quality habitats and doing poorly due to low adult or lamb survival have generally not been successful (Enk et al. 2001). Transplant programs also have the potential to affect negatively the age structure, productivity, and recovery rate of herds used as source herds for transplants (Leslie 1980, Leslie and Douglas 1986, Stevens and Goodson 1993). Estimates of bighorn herd size are difficult to obtain, and they often have wide confidence intervals. Removing 20 bighorns from a large population of 300±50 animals certainly has a lower risk to the source herd than removing 20 bighorns from a source herd estimated to have 125±50 animals.

Hess (1996) and Dubay et al. (2003) suggest that managers need to be aware of the potential disease threats that translocation programs can represent to indigenous wildlife, including resident bighorn sheep. Therefore, augmenting existing populations should be conducted with caution to ensure that diseases are not spread through the mixing of sheep populations. For this reason, managers should not transplant bighorns into sheep populations where no information is available on the disease history of the donor and recipient herds. Disease risk can be significantly reduced by evaluating the health status of bighorns from the source population, as well as from sheep present at the release location.

Traditionally, bighorn harvest management has primarily directed harvest towards the male component of the sheep population, in large part because of the trophy status of mature rams. Although this restrictive harvest strategy generally guarantees that sport harvest is a minor mortality factor in hunted bighorn sheep populations, it may have evolutionary consequences that could result in a general decrease in body weight and horn size over the long term (Coltman et al. 2003). However, limiting mortality by sport hunting will not ensure population viability for many bighorn sheep populations. Research on bighorn sheep die-offs indicates that Pasteurellosis causes pneumonic all-age die-offs in wild sheep populations that come into contact with domestic sheep. However, Pasteurellosis has also been a primary cause of die-offs in several bighorn sheep populations that had no known history of contact with domestic sheep or goats (Goodson 1982, Onderka and Wishart 1984, Foreyt 1989, Ryder et al. 1994). In these latter cases, environmental stressors, associated with high population densities of bighorn sheep, were believed to be possible causes of these die-offs. If pneumonia die-offs are a result of density-dependent environmental stressors, then it is likely that management approaches that place sport harvest emphasis on male sheep, and essentially protect females from harvest, could eventually allow wild sheep populations to increase to the point where they exceed the carrying capacity of their habitat and leave them more vulnerable to density-dependent environmental stressors. Under these conditions, it is likely that overall body condition and productivity of the sheep population will decline, leading to greater vulnerability to disease pathogens, population stagnation, and periodic die-offs. If these conditions occur, it may be possible for state and federal agencies to avoid some die-offs associated with environmental stressors by implementing aggressive management strategies for the female segment of the sheep population through sport hunting and/or translocation programs.

Jorgenson et al. (1993) reported that ewe-hunting seasons had the potential to limit population increase and concomitantly increase trophy ram size when 12 to 24 percent of the ewe population was removed each year over a 9-year period. Based on known summer herd size in their study population with high survival, high productivity, and no predation or disease, Jorgenson et al. (1993) calculated that 12 percent of the ewes could be harvested each year to maintain herd stability. Sport hunting for ewes is a management option suited to most herds while translocations may not be practical for herds in remote or wilderness locations.

Although cougar predation on adult females can represent a serious threat to small, local populations, predation on bighorns generally appears to be sporadic and probably is of relatively little management concern for most bighorn populations in Region 2 (Sawyer and Lindzey 2002). Modeling efforts suggest that in a bighorn population with more than 15 breeding age females, indiscriminant removal of cougars is no more effective in reducing the risk of extirpation of the herd than selective predator control efforts directed at removing individuals that are specializing in killing bighorns (Ernest et al. 2003). Because cougars are territorial and young animals readily disperse into unoccupied cougar habitat, indiscriminant predator control efforts may remove resident cougars that do not routinely kill bighorns. This may result in resident cougars being replaced by immigrating, subadult cougars that may prey heavily on bighorns, especially if alternative prey is not readily available to them (Logan and Sweanor 2001). Selective predator control efforts that are targeted at individual cougars appear to be more effective in areas where bighorn sheep populations are threatened by predation.

Population inventory and monitoring

Monitoring and assessing the status of wildlife populations are two of the most important and challenging tasks that biologists face. Although complete enumeration of bighorn populations provides managers with accurate counts, limited financial resources often dictate that other methodologies be used to estimate wild sheep numbers. Conducting a census on large, free-ranging ungulates, like bighorn sheep, is difficult and expensive because they occupy large areas that are often in remote, rugged terrain, and only a small percentage of the population is usually observed in any survey effort.

Probably the most frequently used methods used to count bighorn sheep are fixed-wing and helicopter counts. Population estimates generated from standard aerial surveys vary considerably depending on topography, weather, observer experience, and vegetative cover. Pitzman (1970) and Heimer (1976) estimated that they observed more than 90 percent of Dall sheep in their surveys while Nichols and Erickson (1969) indicated that they observed between 39 and 51 percent of desert bighorns during their surveys. Helicopter surveys are used most frequently to obtain herd composition estimates, while fixed-wing surveys, conducted during the spring green-up period, are used frequently for estimating total numbers of sheep. Site-specific detection models have been developed to estimate visibility bias during helicopter surveys using sophisticated statistical analyses that correct for animals missed during the census effort (Bodie et al. 1995, Hells Canyon Bighorn Sheep Restoration Plan 2004). Bodie et al. (1995) reported that activity and habitat were the most important factors influencing ability to locate California bighorns visually in a canyon environment in southwestern Idaho. Number of ewes in a group, cover type, and activity were the primary factors that significantly affected the visibility of Rocky Mountain bighorn sheep in Hells Canyon (Hells Canyon Bighorn Sheep Restoration Plan 2004). Census method and timing, in addition to environmental factors, can influence sex ratios observed in the field, and result in considerable variation in reported sex ratios (Buechner 1960).

In addition to aerial surveys, biologists use ground counts to obtain minimum numbers of sheep and to develop reconstructed population estimates (Wehausen 1980). Wehausen (1980) used the reconstructed population approach for developing estimates of Sierra Nevada bighorn sheep by classifying sheep by age and sex in consecutive years and adding any animals counted in the current year, but missed in the previous year's count, to the previous year's total. Minimum counts and reconstructed population estimates have utility in areas where biologists have a good understanding of herd behavior and seasonal distribution, where bighorns are concentrated, and where multiple counts can be made in a relatively short time frame. Minimum counts that focus on the female component of the herd yield certainty in the numbers of animals observed and have the built-in buffer of animals not accounted for in the survey. Valdez and Krausman (1999) suggested that lamb:ewe ratios were the best indicator of population status and that winter ratios falling below 25:100 were cause for concern. However, Festa-Bianchet (1992) and Jorgenson (1992) suggested that lamb:ewe ratios were not a reliable indicator of population condition, but if calculated in June, they may be a reasonable predictor of yearling recruitment (Festa-Bianchet 1992).

A number of researchers have used mark-resight techniques to obtain population estimates for bighorn sheep, with varying degrees of success (Furlow et al. 1981, Neal et al. 1993, George et al. 1996). A variety of models are currently available to adjust results generated by mark-resight methods to meet the basic assumptions (e.g., equal sightability probabilities, population closure) that form the foundation for those estimates.

A promising technique for estimating population size involves genotyping bighorn sheep from DNA extracted from fecal samples (Taberlet et al. 1996, 1999). This approach is most appropriate for small herds and can be done in conjunction with efforts to document genetic variability in isolated bighorn herds. Other methods, including water hole and mineral lick counts, foot and horseback transects, and boat surveys, have been used to count bighorns in parts of their range where appropriate. It is important to use the most appropriate, systematic, and repeatable methods possible to develop a better understanding of bighorn population trends.

Habitat management

Habitat conservation is an essential component of bighorn sheep management. It should involve efforts to identify, map, and protect crucial bighorn habitats and the landscape linkages that join them. Managing wildlife species through the management of their habitat is an indirect, but effective approach for ensuring the long-term persistence of bighorn sheep, and it is a critical element of bighorn conservation. Elements of any habitat management approach include identifying important habitat variables for bighorn sheep, mapping these characteristics on a landscape level, developing management prescriptions to protect these habitat characteristics, and applying management emphasis to high priority areas.

Two fundamental habitat issues affect the long-term viability of bighorn sheep in Region 2, habitat loss and habitat fragmentation. Although federal land management agencies manage most bighorn habitat in Region 2, habitat losses do occur because of the presence of domestic livestock allotments, overgrazing by domestic livestock, fire suppression, and human disturbance on crucial ranges from recreational activities and development. Furthermore, highways through national forests are increasingly becoming barriers to movement as vehicle traffic volume increases and the highways are expanded to accommodate those volume increases.

One of the primary benefits of a well-designed habitat management program is that it will act as a buffer against many of the uncertainties inherent in bighorn population management. Specifically, when bighorn populations dip below desired levels, the presence of abundant, high quality habitat provides for resiliency that would not exist if the habitat to support bighorn sheep were marginal. Habitat enhancement efforts can make unoccupied habitats available to bighorns or create additional habitat by providing limited resources (water or forage) by logging heavily forested areas adjacent to occupied bighorn habitat or using prescribed burns to improve forage quality and production on critical ranges (Arnett 1990, Cook 1990).

Although bighorn sheep are adapted to a wide variety of topographic features in Region 2, one common denominator describes bighorn habitat in the Region: they prefer semi-open, precipitous terrain characterized by a mixture of steep and gentle slopes, broken cliffs, rocky outcrops, and canyons. Escape cover is a critical habitat attribute for adult ewes, even more important than high quality forage (Festa-Bianchet 1989a, Cook 1990). The quantity of escape terrain can be an accurate predictor of ewe numbers on the winter range (Leslie and Douglas 1979, Ebert and Douglas 1993). Visibility is another critically important habitat variable for bighorn sheep. Consequently, vegetation structure is probably more important to bighorns than plant composition because vegetation types that permit high visibility allow for the detection of predators (Risenhoover and Bailey 1985, Wakelyn 1987).

Vegetation structure and composition are strongly influenced by climate, elevation, latitude, and to a varying extent by land management practices. Because very little can be done to modulate the effects of climate (and nothing about elevation or latitude), land managers focus their habitat management and conservation efforts on developing and implementing long-range, multiple-use land management plans. In the case of the USFS, the forest planning effort involves balancing input from a diverse group of stakeholders with different management priorities. A number of activities allowed on National Forest System lands, including domestic livestock grazing, timber removal, fire suppression, and habitat restoration projects, have the potential to affect the quantity and quality of habitat available to bighorn sheep in the Region.

One of the more important activities that directly affect bighorns is domestic livestock grazing in bighorn sheep habitat. Bighorns are negatively impacted by disease transmission from domestic livestock, especially domestic sheep and goats. Areas that have been grazed by domestic sheep may not be suitable areas for wild sheep for up to four years after grazing has been discontinued (Jessup 1985). Bunch et al. (1999) suggested that domestic and wild sheep should never be allowed to occupy the same areas because of the potential for disease transmission and the risk of a major die-off. Federal land managers, livestock owners, and private conservation groups have worked closely together in some areas to minimize the opportunity for domestic and wild sheep to overlap by converting grazing sheep allotments to cattle allotments, purchasing active sheep grazing allotments and retiring them from use, and retiring vacant sheep allotments. However, despite the best efforts of federal land management agencies and conservation organizations, like the Foundation for North American Wild Sheep, to prevent domestic sheep from mingling with wild sheep, domestic sheep can still be found on private in-holdings, on private lands adjacent to National Forest System lands and on active allotments on National Forest System lands adjacent to or within habitat occupied by bighorns.

Cattle grazing can result in a reduction of forage and space available to bighorn sheep by reducing the abundance and availability of preferred forage species and forcing them to compete with other wild ungulates for forage on summer and winter ranges (McCann 1956, Oldemeyer et al. 1971, Estes 1979, Arnett 1990, Cook 1990). Bighorns are facultative generalists in their diet selection, selecting preferred, highly nutritious plant species in the spring and early summer and a larger number of species later in the year (Ginnett and Douglas 1982). Overgrazing by domestic livestock reduces plant abundance and the species composition of bighorn habitats, leading to a decrease in carrying capacity of the habitat. The length of time necessary for overgrazed habitats to regenerate is, in part, a function of the density of animals using the rehabilitated habitat and precipitation levels, with more mesic habitats recovering more quickly than drier sites (Lathrop and Rowlands 1983, Arnett 1990). Domestic livestock grazing in riparian areas and on bighorn summer ranges can also influence lamb mortality rates when bighorn ewes are denied access to high quality forage. Cook (1990) reported a strong correlation between forage quality during summer and early fall and lamb survival in three south-central Wyoming bighorn sheep herds. He concluded that the high mortality rates experienced by those herds resulted from inadequate nutrition that lead to reduced growth rates, poor overall health, and lower disease resistance in lambs. Streeter (1969) indicated that bighorn herds in Colorado that were foraging on high crude protein (over 40 percent) diets during the fall had higher lamb survival. These data suggest that the availability of high quality forage during the summer and early fall may be critical to lamb survival the following winter and may influence their susceptibility to enzootic disease during the mid-summer period (Cook 1990).

Habitat improvement projects for bighorn sheep must reflect their biological requirements and not ignore the fact that they can be poor colonizers and have specific habitat needs that limit their distribution to areas with adequate escape cover (Geist 1971, Wakelyn 1987, Cook 1990). Historically, bighorn sheep habitat improvement projects have focused on water developments in xeric habitats, changes in fence design, and removal of domestic sheep from bighorn ranges.

More recently, land managers have used prescribed burning to create or enhance bighorn habitats. Over the last 40 to 50 years, fire suppression policies have indirectly affected bighorns in Region 2 by allowing changes in vegetation structure on bighorn ranges that often resulted in decreased forage availability, loss of movement corridors, increased vulnerability to predators, and increased competition from other wild ungulates where forests encroach on open habitat types. Prescribed burning projects have considerable potential for reducing vegetation density and increasing forage quality in bighorn habitats impacted by fire suppression policies in the past. Prescribed burns can provide suitable habitat for bighorns where they are adjacent (less than 400 m) to escape cover and are located near the upper part of slopes. Arnett (1990) reported that bighorns in south-central Wyoming consistently avoided areas further than 600 m from escape cover and the lower portion of slopes. For these reasons, prescribed burns should be located near escape terrain and, preferably, adjacent to currently utilized areas. Cook et al. (1989) suggested that prescribed burns located on winter and spring ranges should be oriented to a southern aspect, while burns on north and east aspects provided the best quality forage on summer and early fall ranges. Cool, prescribed burns in the spring resulted in rapid improvement of herb production and reduced mortality of desirable shrub species (Cook et al. 1989). Habitat restoration projects following wild fires or severe overgrazing also have potential to improve habitats for bighorn sheep when they are reseeded in preferred, native plant species. Fertilization has resulted in improved forage production in high elevation rangelands (Laycock 1982) and increased growth rates for perennial grasses in burns and clearcuts (Arnett 1990).

Forest succession resulting from fire suppression policies has resulted in the loss and fragmentation of bighorn habitat and blocked movement corridors. Forest stands adjacent to occupied habitat and located near (less than 400 m) suitable escape cover can be managed to expand the habitat base for herds that are currently at carrying capacity (Arnett 1990). For example, clearcuts can be used to eliminate vegetation overstory and thereby expand the overall habitat base for the herd. Removing timber stands can create or re-open movement corridors that may allow bighorns to move from low elevation ranges to alpine areas, or to reconnect herds. However, management actions designed to increase connectivity among bighorn herds must be evaluated carefully to avoid creating corridors that can be used by bighorns to come into contact with domestic sheep or goats or to transmit disease organisms to naïve bighorn herds.

Clearcuts can also be managed to suppress conifer regeneration and to provide increased forage production, particularly grasses and forbs (Austin and Urness 1982). To maintain clearcuts in optimum condition for use by bighorns, they should periodically be thinned of all conifer regeneration and seeded with sod-forming grasses and forbs (Austin and Urness 1982). Sod-producing grass species were effective in suppressing conifer regeneration in clearcuts (Arnett 1990). Habitat restoration projects that use prescribed burning and clearcuts to increase forage quality and production or to increase the habitat base for bighorns may be an effective mechanism for enhancing the population viability of the many small (less than 100) herds found in Region 2 today. It appears that trapping and transplant programs for bighorns over the last 40 years have been effective at re-establishing or re-populating most suitable bighorn habitat. Additional efforts to translocate bighorns into unoccupied habitat or to augment small populations will likely provide little gain for bighorn management programs. However, habitat restoration may be a realistic method for increasing habitat capability to support larger numbers of bighorns (Arnett 1990).

Habitat inventory and monitoring

In the past, managers have used several approaches, including pattern recognition (PATREC) and habitat suitability index (HSI) models and topographic maps, to evaluate and monitor changes in habitat quality for bighorn sheep. However, many of these methods are subjective, qualitative assessments that are only marginally adequate for predicting habitat suitability. A Geographic Information System (GIS) approach offers a number of advantages to managers because it permits more refined spatial analyses of habitat attributes. GIS now makes it possible to:

(1) quantify attributes within habitat patches or travel corridors on a landscape level

(2) assess patch continuity within and between mountain ranges

(3) identify threats to habitat integrity

(4) assess habitat deficiencies

(5) perform statistical tests on habitat data

(6) simulate changes in habitat under proposed management strategies.

Although landscape level approaches to evaluating and monitoring the status of bighorn sheep habitat are useful to managers, they have limited discriminatory power for measuring changes in plant composition, diversity, biomass, and condition. Excessive grazing by domestic livestock can result in changes in plant composition and density in plant communities that cannot be detected using large, landscape-level analyses. To monitor changes within plant communities effectively, intensive fieldwork will be necessary. Despite the difficulty of defining critical thresholds of habitat degradation and fragmentation, incorporating periodic data from field surveys with GIS approaches can provide managers with a realistic picture of the current condition and trend in bighorn sheep habitat.

Metapopulation theory is an important biological principle, and its use in GIS applications is equally important as a management principle because it promotes regional landscape planning, places emphasis on the importance of "non-traditional" habitats such as travel corridors, and is helpful in identifying isolated herds that may require more intrusive management practices (augmentations) in the future to maintain population viability. GIS layers that may prove helpful to managers include:

- ❖ land ownership and the level of legal protection afforded to the land; public land management agencies have different conservation mandates, so maps of land status should indicate the specific management focus (e.g., multiple-use, designated Wilderness, research natural area, National Park) of mapped parcels; for the same reason, the map should distinguish among private, state, tribal, and federal lands

- ❖ locations of natural or manmade features that constitute barriers or filters to bighorn movements (e.g., paved roads, highways, canals, and railroads)

- ❖ land use: agricultural (e.g., livestock grazing allotments, logged areas), industrial (e.g., major mines or oil and gas production sites), recreation, urban development

- ❖ geographic data on bighorn sheep seasonal distribution and densities

- ❖ vegetation layers delineating major habitat types and plant composition

- ❖ Digital Elevation Models (DEM's) for topographic information

- ❖ presence of intermittent and perennial water sources.

Information Needs

Bighorn sheep are one of the most intensely studied animals in North America, yet there is much that remains unknown about their ecology and habitat relationships, and the dynamics that occur among bighorns, other ungulates, their predators, and human uses on the landscape. Although not an exhaustive list of information needs for bighorn sheep, the following represents areas of research for which many population and habitat managers across the range of wild sheep would like to have additional information:

- factors influencing disease outbreaks in bighorn sheep and the vulnerability of bighorns to diseases associated with contact with domestic livestock and environmental stressors

- dynamics of disease ecology in bighorn sheep (i.e., transmission, host-switching by bacterial pathogens, treatment options, molecular identification of virulent pathogens and host species, and factors influencing lamb survival)

- influence of summer and early fall forage quality and production on the susceptibility of bighorn lambs to enzootic disease, predation, and other mortality factors

- relationship among cougars, their primary prey, and bighorn sheep habitat condition as it influences cougar predation levels on bighorn sheep

- reliable maps depicting bighorn sheep distribution, density, habitat quality, and landscape linkages

- reliable estimates or indices of bighorn sheep abundance

- factors affecting the long-term success of transplant and augmentation efforts for bighorn sheep

- effects of sport hunting harvest on bighorn sheep populations; especially the relationship between the harvest of adult ewes and the incidence of disease outbreaks

- landscape scale analyses of the genetic population structure of existing herds to understand the implications of management decisions based on metapopulation dynamics

- metapopulation relationships among small, apparently isolated bighorn herds

- relationship between environmental factors (e.g., fire suppression, grazing, noxious weeds, competition, trace elements) on habitat quality and disease incidence in bighorn sheep

- factors affecting bighorn habitat suitability and capability, including human disturbance, use of habitat linkages, and exploration movements

- bighorn sheep habitat use patterns and responses to habitat changes

- models on bighorn metapopulation dynamics

- models for bighorn habitat use

- developing a vaccine to interrupt the attachment of pneumonia leukotoxins to healthy neutrophil cell-surface proteins.

Although many important research needs can be identified to enhance bighorn sheep management, two areas appear particularly noteworthy, disease ecology including research into the prevention or interruption of disease progression, and habitat loss. Disease probably represents the most serious threat to bighorn sheep across their range. Managers need a better understanding of the dynamics associated with disease transmission between domestic livestock and bighorn sheep. Although research is currently underway to identify the many strains of Mannheimia and Pasteurella and the mechanisms for disease development when passed from domestic sheep or goats to bighorns, much remains to be learned about these supposedly commensal organisms. Another area where research may produce significant gains in our understanding of bighorn sheep management is how metapopulation management strategies influence genetic variability and long-term population viability of bighorns. Habitat fragmentation and loss will ultimately lead to greater isolation of some bighorn herds. Developing a better understanding of how habitat connectivity can aid the management of small, isolated herds will help managers make enlightened land management decisions.

List of Errata

11/2/07 Page 49-50: The Alamosa Canyon and Conejos herd is incorrectly assigned to the San Juan National Forest, but actually occurs on the Rio Grande National Forest. Thus, the Rio Grande has 4 herds, rather than 3, and the San Juan has 5 herds, rather than 6.

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Appendix A

Colorado Herd Units and Hunt Areas for Bighorn Sheep

Table A1. Colorado Herd Unit Names and Associated Hunt Areas.

Herd Name	Hunt Area(s)	Herd Name	Hunt Area(s)
Poudre River	S1	Conejhos River	S30
Gore-Eagles Nest	S2	Blanco River	S31
Mount Evans	S3	Georgetown	S32
Grant	S4	Rampart Range	S34
Pike’s Peak	S6	Greenhorn	S35
Arkansas	S7	St. Vrain	S37
Huerfano	S8	Apishipa	S38
Sangre de Cristo	S9	Basalt	S44
Trickle Mountain	S10	Dome Rock	S46
Collegiate, North	S11	Brown’s Canyon	S47
Buffalo Peaks	S12	Carrizo Canyon	S48
Snowmass, East	S13	Grape Creek	S49
Sheep Mountain	S15	Mt. Maestas	S50
Cinnamon Peak	S16	Spanish Peaks, Culebra	S51
Collegiate, South	S17	Bristol Head	S53
Rawah	S18	West Elk-Dillon Mesa	S54
Never Summer Range	S19	Natural Arch, Carnero	S55
Marshall Pass	S20	Big Thompson Canyon	S57
Cow Creek	S21	Derby Creek	S59
San Luis Peak	S22	Shelf Road	S60
Kenosha	S23	Purgatorie Canyon	S61
Snowmass, West	S25	Costilla	S65
Taylor River	S26	Mt. Elbert	S66
Tarryall	S27	White River, South Fork	S67
Vallecito	S28	Cotopaxi	S68
Alamosa Canyon	S29	Lower Cochetopa Canyon	S69

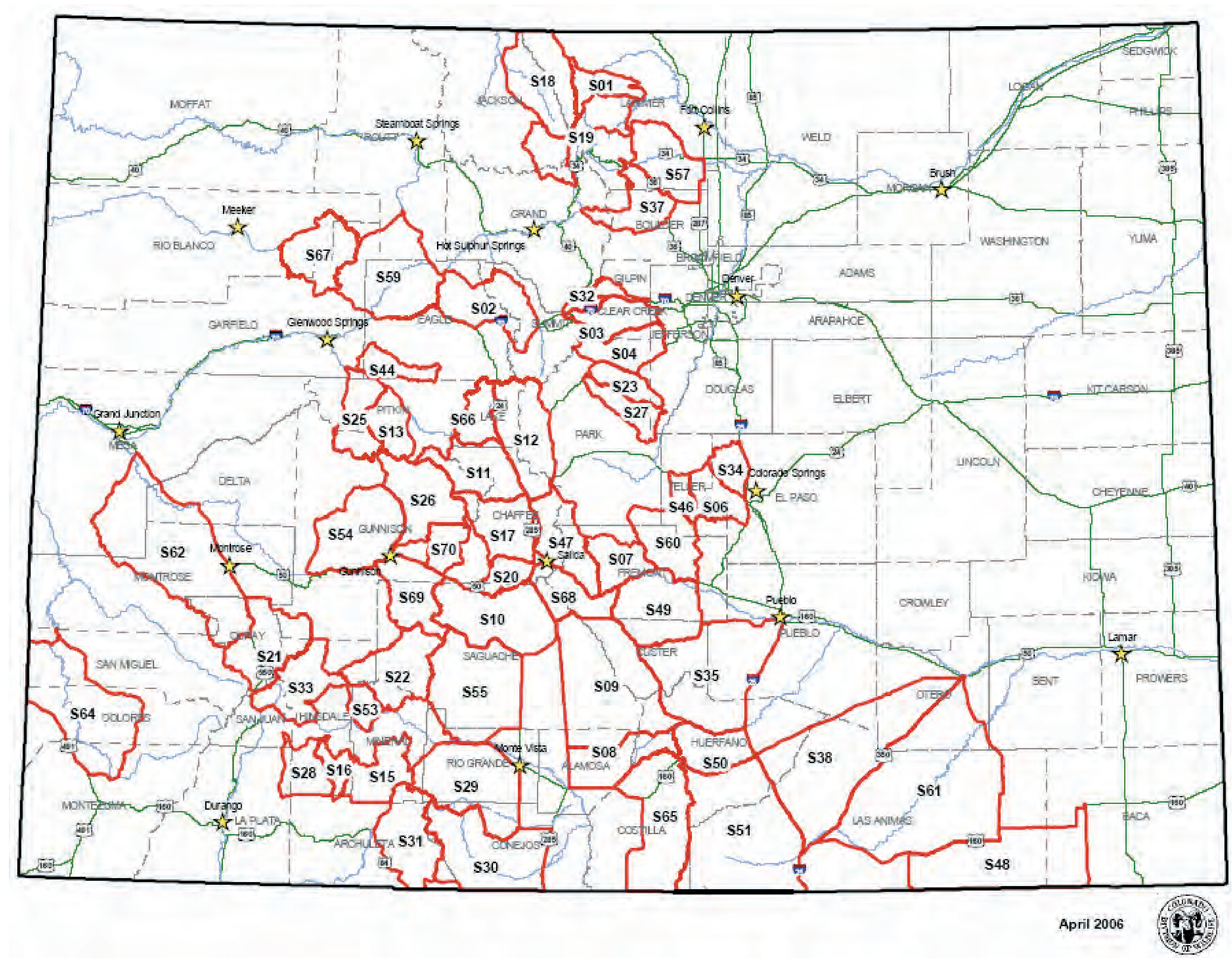

Figure A1. Colorado Bighorn Sheep Hunt Areas.

Appendix B

Wyoming Herd Units and Hunt Areas for Bighorn Sheep

Table B1. Wyoming Herd Unit Names and Associated Hunt Areas.

Herd Unit	Hunt Area(s)
Targhee	6
Jackson	7
Darby Mountain	24
Clarks Fork	1
Trout Peak	2
Wapiti Ridge	3
Youts Peak	4
Francs Peak	5, 22
Devils Canyon	12
Douglas Creek	18
Laramie Peak	19
Encampment River	21
Whiskey Mountain	8, 9, 10, 23
Temple Peak	11
Sweetwater	16
Seminole/Ferris	17

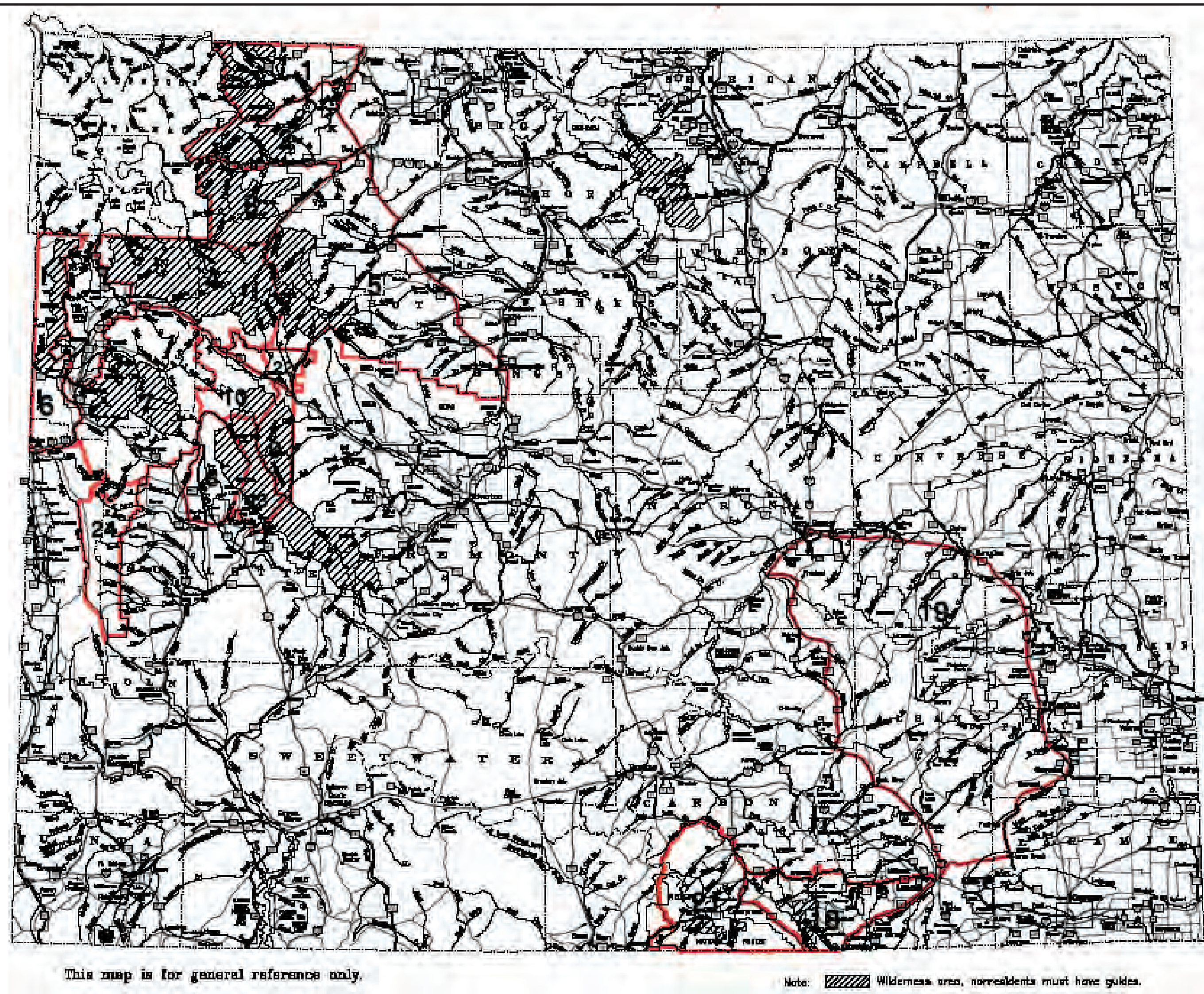

Figure B1. Wyoming Bighorn Sheep Hunt Areas.